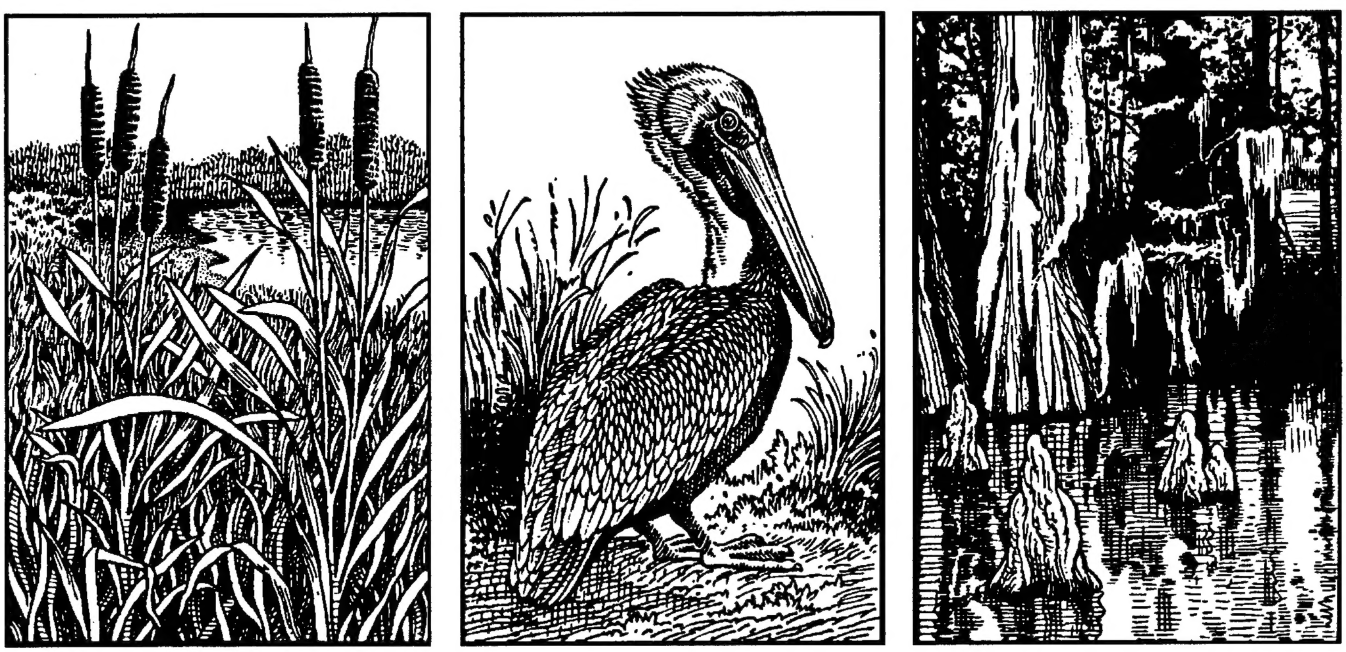
US Army Corps
of Engineers
Waterways Experiment
Station

Wetlands Research Program Technical Report WRP-RE-14

Reestablishment of Bottomland Oak Species in Lower Mississippi Valley Alluvial Soils

by Masato Miwa



October 1995 – Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

Technical Report WRP-RE-14
October 1995

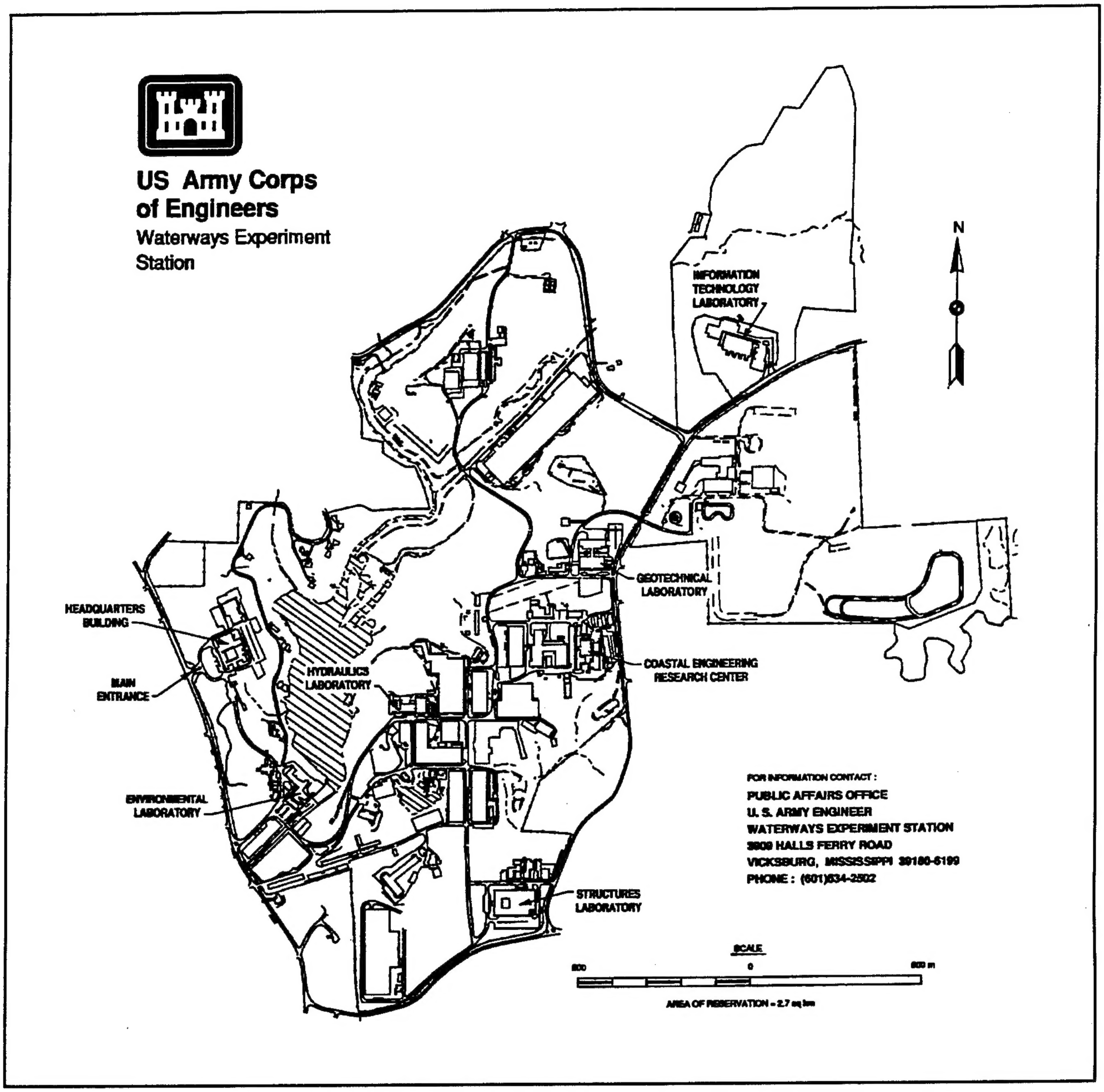
Reestablishment of Bottomland Oak Species in Lower Mississippi Valley Alluvial Soils

by Masato Miwa

Mississippi State University
Mississippi State, MS 39762-9681

Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

Miwa, Masato.
Reestablishment of bottomland oak species in lower Mississippi Valley alluvial soils / by Masato Miwa ; prepared for U.S. Army Corps of Engineers.
52 p. : ill. ; 28 cm. -- (Technical report ; WRP-RE-14) (Wetlands Research Program technical report ; WRP-RE-14)
Includes bibliographic references.
1. Oak -- Mississippi River Valley. 2. Forest management -- Mississippi River Valley. 3. Wetland conservation -- Mississippi River Valley. I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Wetlands Research Program (U.S.) IV. Title. V. Series: Wetlands Research Program technical report ; WRP-RE-14. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; WRP-RE-14.
TA7 W34 no.WRP-RE-14

Corps of Engineers Research Report Summary, October 1995

Forested Wetlands Restoration

Reestablishment of Bottomland Oak Species in Lower Mississippi Valley Alluvial Soils (TR WRP-RE-14)

ISSUE:

The majority acreage of bottomland hardwood forests in the lower Mississippi Valley have been cleared. Several Government programs now encourage reforestation of formerly cleared areas, especially to large seeded tree species. Research is needed to identify optimal planting methodologies to utilize soil and hydrologic gradients and species diversity if bottomland forests are to be economically reforested and managed.

RESEARCH:

Four of the most commonly planted oak species were planted in both seed and seedling form onto three of the most common farmland soils available for bottomland hardwood restoration. Replicated treatments were oak species, soil series, and planting methodology. Soil physical, hydrologic, and fertility properties were correlated with plant germination and growth for each species. Anticipated treatment differences were muted by ideal growing conditions in the first year of the study.

SUMMARY:

.Optimal soil moisture conditions during the spring and growing season of 1992 enhanced germination, survival, and growth and minimized treatment differences. Nuttall and water oak seemed to exhibit germination and growth patterns that may enhance their survival under more stressful growing conditions. Differences in soil type and planting methodology were generally nonsignificant.

AVAILABILITY OF REPORT:

This report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4650. For help in identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

About the Authors:

Masato Miwa was a graduate student of forestry at Mississippi State University and continues his studies at Virginia Polytechnic Institute. Point of contact at WES is Dr. Stephen Sprecher at (601) 634-3957.

Contents

List of Figures

List of Tables

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE) as part of the Restoration and Establishment Valuation Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32761, "Wetlands Field Demonstrations and Research," for which Dr. Mary C. Landin, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was Technical Manager. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for this work.

Mr. Dave Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, WES, was the Wetlands Program Manager. Dr. Landin was the Task Area Manager.

The work was performed at Mississippi State University under the direct supervision of Drs. Hans Williams and Steven W. Sprecher, Wetlands Branch (WB), Ecological Research Division (ERD), EL. This report was prepared by Mr. Masato Miwa, under contract, as part of his Master Degree program under the guidance of Dr. Stephen Schoenholtz, Soil Scientist, Mississippi State University. The work was conducted under the general supervision of Mr. Ellis J. Clairain, Acting Chief, WB, Dr. Conrad J. Kirby, Chief, ERD, Dr. Edwin A. Theriot, Assistant Director, EL, and Dr. John W. Keeley, Director, EL.

The majority of this report has been printed previously as Mr. Miwa's Masters thesis. The Masters thesis contains extra appendices of actual data sets and can be obtained from University Microfilms, Ann Arbor, MI. A copy also resides in the Mississippi State University Library. All data in this report and in the thesis are property of WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

Miwa, M. (1995). "Reestablishment of bottomland oak species in lower Mississippi Valley alluvial soils," Technical Report WRP-RE-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction

History and Trend of Wetlands

Since the colonial period (17th century), large areas of United States wetlands have been converted into economically useful lands for farming, residential, or industrial sites. This is mainly because the early American society did not realize the functions and values of intact wetlands, rather they considered wetlands as waste areas (Burke et al. 1988). The United States has lost more than half of its original wetlands (Burke et al. 1988). The estimated total original wetland area was about 87 million hectares. The remaining wetland area is approximately 36.4 million hectares of which 95 percent is inland freshwater wetlands (Want 1989). The estimated rate of loss during the 1960s and 1970s was about 121,500 to 186,000 ha per year, and about 80 to 87 percent of these losses were agricultural developments of inland wetlands (Want 1989).

Wetland development in the lower Mississippi Valley region started in 1726 with levee construction to protect the city of New Orleans (Council on Environmental Quality 1978). Wetland conversion was very slow until the 1930s because of manual construction limitations. Conversion was accelerated during the 1960s and 1970s with the mechanization of land clearing and farming operations, expansion of the soybean market, and governmental subsidies for cropland development (Council on Environmental Quality 1978). Forested wetlands have decreased by 31 to 48 percent of the original area since the 1950s, with about 81,000 ha of the forests being cleared annually (Council on Environmental Quality 1978). As a result, about 78 percent of the original forested wetlands are estimated to have been lost in the South (MacDonald, Frayer, Clauser 1979; Burke et al. 1988).

The public has recently realized and begun to appreciate the beneficial values of wetlands. Because of increased environmental concerns and growing awareness of wetland losses, conversion has become a sensitive issue, and pressures have mounted for wetland preservation and restoration. Despite current public consensus for protection, wetland areas have been decreasing every year (Turner, Forsythe, and Craig 1981).

Wetland Regulation and Restoration

The U.S. Army Corps of Engineers (Corps) with oversight from the U.S. Environmental Protection Agency (EPA) was authorized to regulate wetland development and to conduct wetland mitigation programs based on Section 404 of the Federal Water Pollution Control Act of 1972 (FWPA), known as the Clean Water Act (CWA) (Kruczynski 1989). The Corps' fundamental regulation policy is wetland preservation (Hill 1975).

Numerous wetland development plans are proposed to the Corps every year. Each plan is reviewed and examined regarding its location, effects on adjacent wetlands, and alternative wetland mitigation plans based on Section 404, CWA. Despite detailed considerations and strict mitigation requirements for wetland developments, only two-thirds of the converted wetland areas have been mitigated (Kruczynski 1989).

Although wetland mitigation programs have been considered as effective tools to minimize wetland losses, they are limited by a number of factors such as loss of present wetland values, cost of new wetland creation or restoration, and time to create new functional wetlands (Kruczynski 1989). In fact, there are many restoration uncertainties such as appropriate wetland evaluation methods and standards, comparison methods between intact wetlands and mitigation sites, suitable species to restore wetland vegetation, and the monitoring system used during the mitigation process (Kruczynski 1989).

Justification

Restoration of forested wetlands is critical because of historical and current rates of loss (Burke et al. 1988; Want 1989). However, limited information exists about wetland species-site relations regarding reestablishment of forested wetland tree species (Kruczynski 1989). In particular, there is a lack of knowledge about heavy-seeded hardwood germination and seedling performance in wetland soils in relation to wetland hydrology and specific soil characteristics. The overall objective of this study is to evaluate the reestablishment of cherrybark oak (*Quercus pagoda* Raf.),[1] Nuttall oak (*Q. nuttallii* Palmer), Shumard oak (*Q. shumardii* Buckl.), and water oak (*Q. nigra* L.) in relation to soil and hydrologic characteristics of three common lower Mississippi Valley alluvial soils, and other environmental factors such as soil temperature, soil moisture, and herbaceous competition.

[1] All scientific names and author names of tree species are based on Duncan and Duncan (1988).

The following specific objectives were examined to investigate bottomland oak species reestablishment:

a. Compare soil temperature, soil moisture, and soil physical and chemical properties among the three soil series.

b. Determine subsurface groundwater level, perched water level, and flooding level, frequency, and duration in the three soil series.

c. Compare the effect of two planting methods on oak seedling establishment and growth.

d. Compare total germination, seedling survival, and seedling growth among the four oak species.

e. Determine the effect of soil temperature on germination rates and mortality rates.

f. Determine the effect of soil moisture levels on germination rates and mortality rates.

g. Determine the effect of flooding level, duration, and frequency on germination rates and mortality rates.

h. Determine the effect of soil chemical and physical properties on total germination, seedling survival, and seedling growth.

i. Determine the effect of competing herbaceous biomass on total germination, seedling survival, and seedling growth.

2 Materials and Methods

Materials

Study location

This study is part of the Lake George Wildlife Wetland Restoration Project (Lake George Project), which was designated by the Corps for the mitigation of terrestrial wildlife losses resulting from the Yazoo Area and Satartia Area Backwater Levee Projects (U.S. Army Corps of Engineers 1990). The 3,300-ha project site was converted from bottomland hardwood forest to agriculture in the 1960s and has been intensively farmed in cotton, soybeans, and rice. The project site is in Yazoo County, Mississippi (Figure 1), and is bounded by the Delta National Forest on the southwest and by the Panther Swamp National Wildlife Refuge on the northeast. One of the objectives of the Lake George Project is to reestablish a bottomland hardwood forest that will connect these two fragmented, large forest systems.

Soil series

Three common soil series that represent a range of edaphic conditions commonly occurring on the site and throughout the Lower Mississippi Valley alluvial floodplain were studied: (a) Dundee (fine-silty, mixed, thermic, Aeric Ochraqualfs) is a somewhat-poorly drained soil formed on old river ridges characterized by slight elevation above adjacent areas (Soil Conservation Service-U.S. Department of Agriculture (SCS-USDA) 1975); (b) Forestdale (fine, montmorillonitic, thermic, Typic Ochraqualfs) (SCS-USDA 1975) occurs in lower landscape positions and is poorly drained; and (c) Sharkey (very fine, montmorillonitic, nonacid, thermic, Vertic Haplaquepts) (SCS-USDA 1975) occurs along drainages or low areas and is characterized by poor drainage because of the high clay content. The Forestdale and Sharkey series are classified as hydric soils (SCS-USDA 1991).

Figure 1. Lake George Project site location in Mississippi

Seedlings and acorns

One-year-old, nursery-grown seedlings were hand-planted in December 1991, and acorns were hand-planted at a depth of 5 to 8 cm in March 1992. Seedlings were obtained from the Delta View Nursery in Leland, MS, and from the Mississippi Forestry Commission Nursery in Winona, MS. Nuttall oak acorns were collected in the Mississippi Delta region, and cherrybark, Shumard, and water oak acorns were collected near Starkville, MS.

Study design

The study design is a randomized complete block design with split-split plots. Four blocks were established within the restoration site (Figure 2). Each block included three soil series (Dundee, Forestdale, and Sharkey) as main treatment plots and four randomly assigned oak species (cherrybark oak,

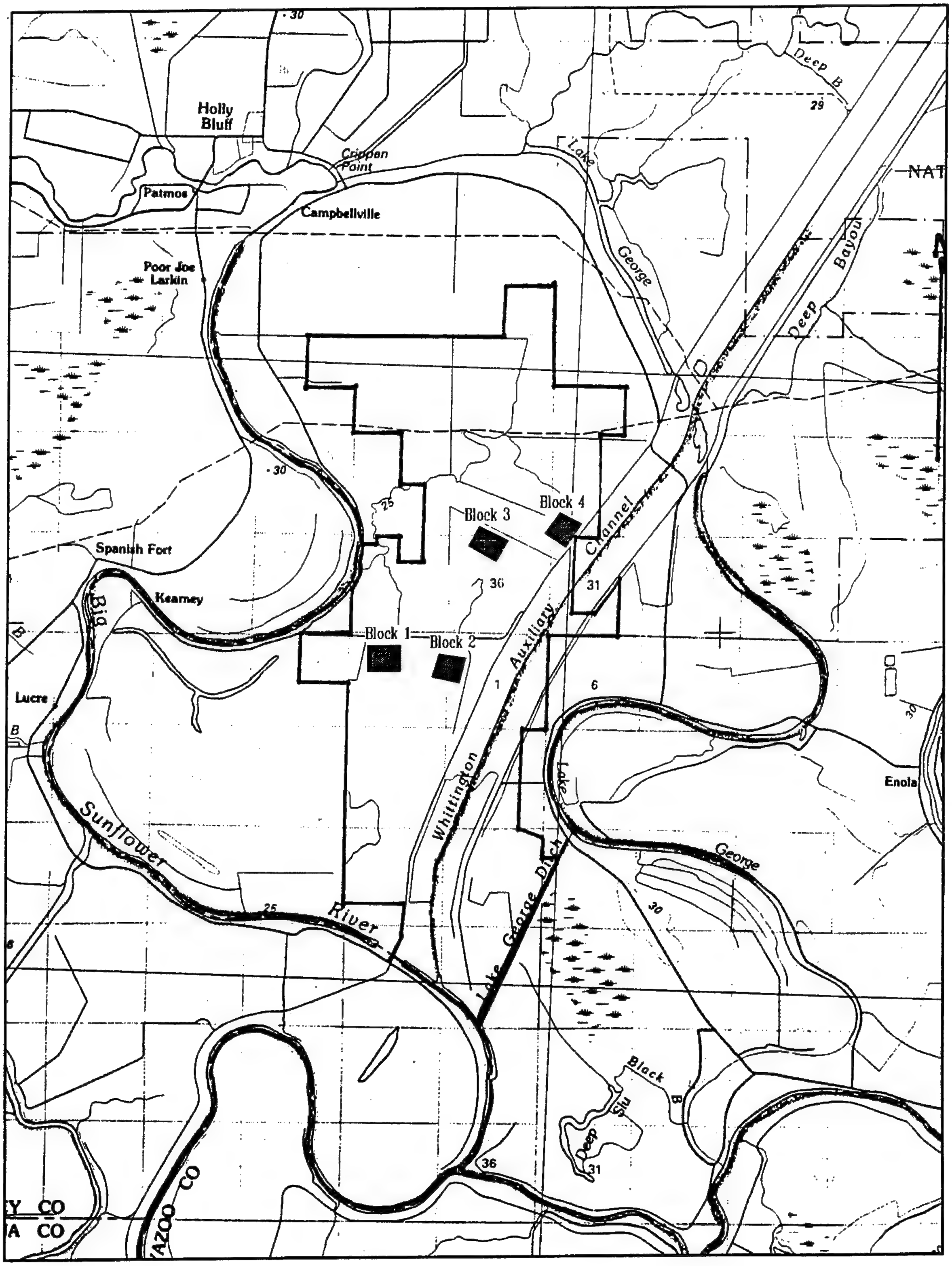


Figure 2. Block locations at Lake George Project site

Nuttall oak, Shumard oak, and water oak) as split plots (Figure 3). Two planting methods (direct seeding and seedling planting) were randomly assigned to split-split plots (Figure 3). Each split-split plot was planted in seven rows with seven planting locations per row at 3- by 3-m spacing. Each split-split plot included 49 planting locations consisting of 24 buffer locations surrounding 25 measurement locations (Figure 3). Approximately 2,400 seedlings (1 seedling per location) and 4,700 acorns (2 acorns per location) were planted.

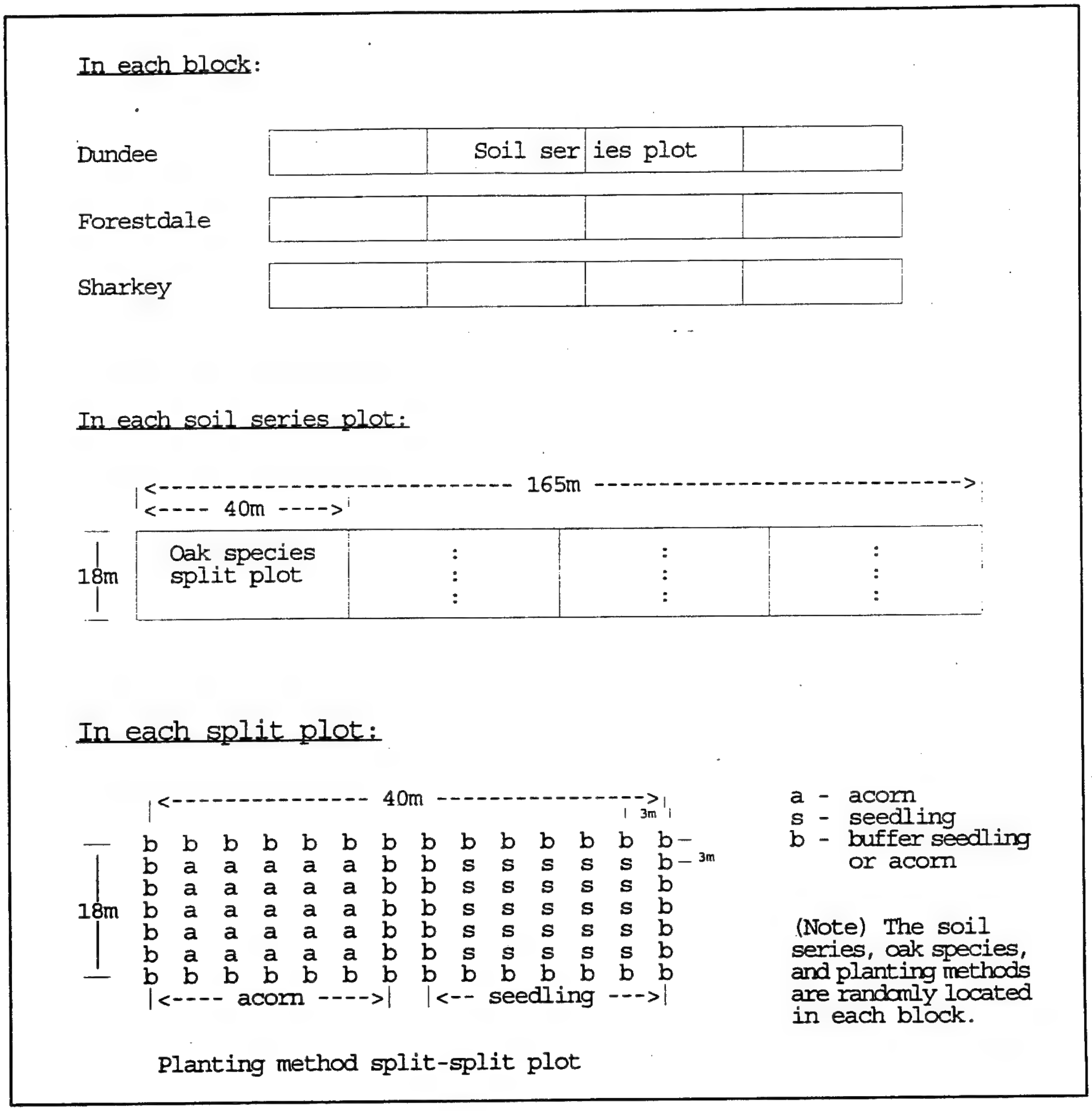


Figure 3. Schematic of study layout for bottomland oak species reestablishment study

Measurements

Hydrology

Two types of wells were used to measure groundwater levels (Figure 4). Wells placed to a depth of 1 m were used to determine the existence of perched soil water, and wells placed to a depth of 3 m were used to measure subsurface groundwater levels. One-meter wells were installed in the center of each split-plot, and three-meter wells were installed in the center of each plot. Perched water levels and subsurface groundwater levels were measured every 2 weeks from January 15 through August 5, 1992, and then monthly through October 1, 1992.

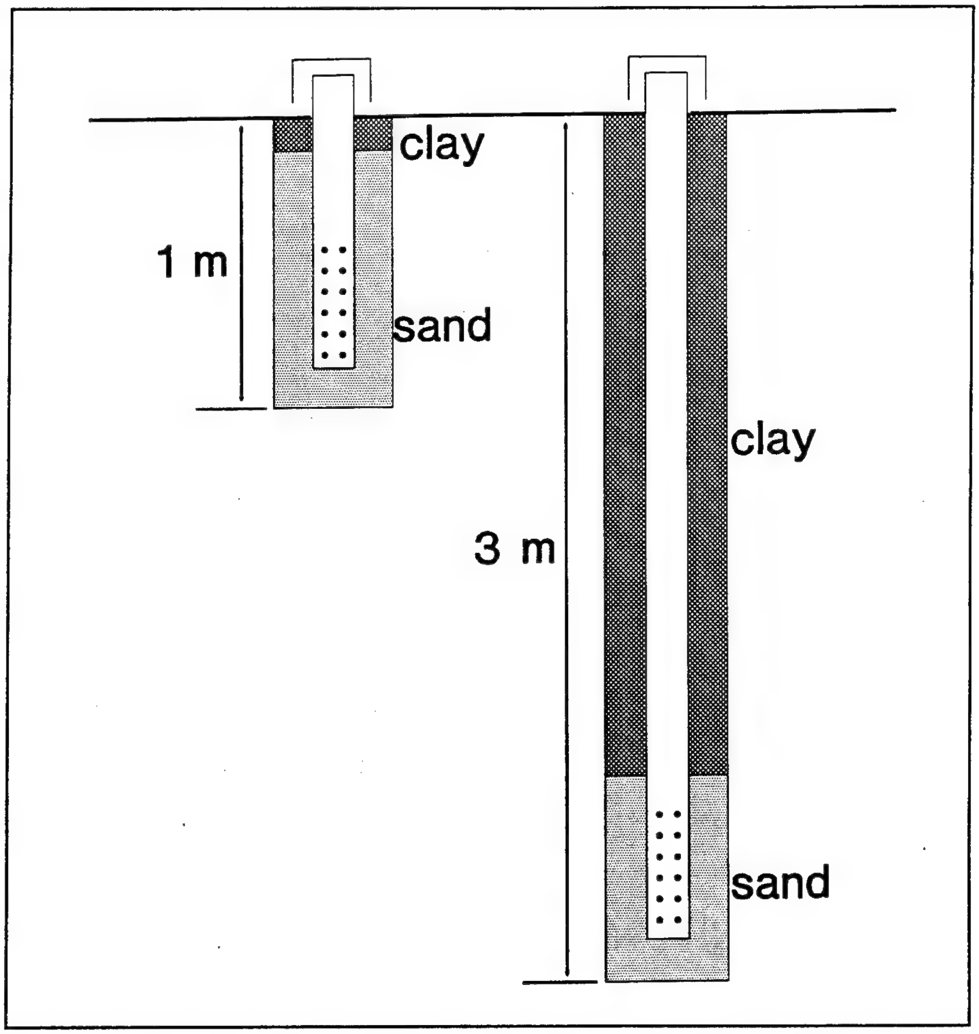


Figure 4. Groundwater monitoring wells used at Lake George Project

The wells were made of polyvinyl chloride (PVC) pipe with 5-cm inside diam and 5-mm wall thickness. The bottom of each well was plugged with a PVC cap. Perforations of 3-mm diam were drilled in the plug and perforations

of 1.5-mm diam were drilled along the bottom 30 cm of each well to create a perforated screen. PVC casing for 1- and 3-m wells was placed in 8-cm diam well excavations. For the 1-m wells, the space between the casing and the soil was filled with silica sand to the ground surface and sealed with clay retained from the excavation (Figure 4). The 3-m wells were placed in the same manner except sand was used to fill only the space between the 30-cm screen and the soil, and the remaining space above the screen was filled with bentonite clay pellets to seal the well from surface leakage.

Flood gauges 2 m in height were established at the lowest elevation split-plot in each block to determine surface water levels and duration if flooding occurred. Flooding level was monitored in cooperation with State agency personnel when the site was flooded. Elevations of all wells and gauges were determined by level survey to standardize the relative elevations of each well and flood gauge.

Onsite precipitation was measured daily from February through June 1992, using a rain gauge in cooperation with a local resident. Additionally, local weather station data, which included precipitation and atmospheric temperature from January through October 1992, were obtained. The nearest local weather stations were located in Yazoo City, which was 26.5 km northeast of the study site, and in Rolling Fork, which was 22.5 km northwest of the study site.

Competition

Herbaceous vegetation biomass was analyzed in July 1992, using 1-m^2 clip plots in each split-split plot and oven-drying the samples at 70 °C until constant weights were achieved. This measurement estimated vegetation dry-weight biomass per unit area.

Soils

Soil temperature was measured in each split plot at a depth of 15 cm every 2 weeks from January 25 through August 5, 1992, and then monthly through October 1, 1992.

An integrated soil moisture reading was taken at 0- to 30-cm soil depth every 2 weeks from January 25 through August 5, 1992, and then monthly through October 1, 1992. Measurements were made at a central location in each split-split plot using either Time Domain Reflectometry or gravimetric sampling. These data were converted to soil water potential values using soil water desorption curves.

The soil water desorption curves were developed by conducting a standard soil moisture characteristic test (Klute 1986). Intact soil samples of 5-cm diam and 1.5-cm height that were collected within three depth ranges (0 to 10, 11 to 20, and 21 to 30 cm) in each split-plot were used. Each sample was soaked

for at least 24 hr, then placed on a porous ceramic plate in a pressure chamber. Various pressures (33, 100, 300, 500, and 1,500 kPa) were applied from low to high pressure, and the sample weight loss was measured after each pressure was applied to establish soil moisture content at each corresponding soil water potential.

Soil moisture retention capacity was also determined from the soil moisture characteristic test. Moisture retention capacity was the difference in gravimetric moisture content between -33 kPa (field capacity) and -1,500 kPa (Richards 1965).

Intact soil samples were used to analyze bulk density, saturated hydraulic conductivity, and macroporosity, microporosity, and total porosity. Intact samples of 7.5-cm diam and 7.5-cm height were collected at depths of 0 to 10, 11 to 20, and 21 to 30 cm from each split-plot using a double-cylinder core sampler. Saturated hydraulic conductivity was analyzed by either the constant head method or the falling head method (Klute and Dirksen 1986). The constant head method was used for samples with conductivity greater than 1.75 cm day^{-1}, and samples with conductivity less than 1.75 cm day^{-1} were analyzed by the falling head method.

Porosity of intact soil cores was measured by using funnels with fritted disks (4- to 5.5-µm pore-size ceramic plate). Macroporosity was determined by applying 50 cm of water pressure to saturated samples to push water from macropores with diameters larger than 0.06 mm (Teare and Peet 1983; Brady 1984). Microporosity was measured as the sample weight loss between the macroporosity measurement and 105 °C oven-dry measurement. Total porosity was the summation of macroporosity and microporosity measurements.

A 2-cm-diam push tube was used to collect composite soil samples from each split-split plot for chemical analyses and soil particle-size analysis. Composite samples were comprised of five subsamples collected at 0- to 30-cm depth. Samples were air-dried, ground, and sieved through a 2-mm screen prior to analysis. Soil particle size was analyzed by the hydrometer method (Gee and Bauder 1986). Clay content was measured 2 hr after the sample was settled. Sand content was determined by measuring the oven-dry weight of the soil fraction retained by a 270 mesh sieve.

Analysis of soil pH, organic matter, extractable phosphorus, and exchangeable potassium, calcium, magnesium, and zinc were conducted by the Soil Testing Laboratory of the Mississippi State Cooperative Extension Service. Soil reaction was determined in the supernatant of a 1:2 soil/water slurry with a pH electrode (McLean 1973). Organic matter was analyzed by the DeBolt procedure (DeBolt 1974). Extractable phosphorus and exchangeable potassium, calcium, magnesium, and zinc were determined by the Lancaster method (Lancaster 1970). Extractable inorganic nitrogen (NH_4^+-N and NO_3^--N) was extracted by 2M KCl solution and was measured by colormetric determination with a Technicon Autoanalyzer II (Technicon Industrial Systems 1973).

Seedling performance

Seedling performance was evaluated by laboratory-controlled tests and field measurements. The controlled seedling and acorn tests were conducted to evaluate seedling and acorn quality at the time of field planting. The seedling test was conducted at the Blackjack Research Area greenhouse with 12 randomly selected seedlings of each oak species. Each seedling was planted in a 10-ℓ pot using a ratio of 1:1 potting soil:sand mixture. The seedlings were placed in the greenhouse from December 1991 through March 1992. Seedlings were watered frequently to maintain moist soil conditions. Seedling viability was evaluated in March 1992.

The acorn test was conducted in a laboratory germinator (Bonner and Vozzo 1987). After several weeks of stratification at 2 to 5 °C, 200 randomly selected acorns of each of the four oak species were soaked in water for 24 hr. Each acorn was cut in half (the side that had the cup scar was discarded), and the pericarp was carefully removed from the side that had the embryo. The specimens were placed on moist blotters with the cut side down and were incubated for 28 days with 8 hr of light at 30 °C and 16 hr without light at 20 °C per day to test for germination.

In the field, acorn germination, germinant survival, and sprouting were measured every 2 weeks from May 2 through August 5, 1992, and then monthly through October 1, 1992. Germinant mortality and sprouting during the growing season were expressed as mortality and sprouting rates. First-year survival, total height, and groundline diameter were measured October 1, 1992.

Planted seedling survival, mortality rate, and sprouting were measured every 2 weeks from May 15 through August 5, 1992, and monthly through October 1, 1992. Mortality and sprouting during the growing season were expressed as mortality rate and sprouting rate. Seedling mortality prior to May was difficult to determine because of high variability in growth initiation. All test seedlings were measured for total height in February 1992 at the beginning of the first growing season and for total height and groundline diameter at the end of the growing season (October 1992). Groundline diameter was not measured at the beginning of the first growing season because of instability and settling of the ground surface after planting disturbance. First-year seedling survival was also assessed in October 1992.

Statistical analysis

Analysis of variance (ANOVA) and Pearson product-moment correlation procedures in the Statistical Analysis System (SAS) were used to test the hypotheses at the 0.05 significance level (SAS Institute, Inc. 1988). Two ANOVA models were used with Duncan's multiple range test to compare treatment means (Tables 1 and 2). Prior to analysis, arcsin transformations were conducted on data that were expressed as percentage values to normalize their distributions.

Table 1
ANOVA Table Used for Seedling Performance, Soil Chemical Properties, Soil Particle-Size Analysis, Soil Temperature, Soil Water Potential, Soil Erosion and Deposition, and Herbaceous Vegetation Biomass Hypothesis Testing

	Source[1]	DF
Main Plot	Blk	3
	Sol	2
	Blk × Sol (Error A)	6
Split Plot	Spp	3
	Sol × Spp	6
	Sol × Spp × Blk (Error B)	27
Split-Split Plot	Plm	1
	Sol × Plm	2
	Spp × Plm	3
	Sol × Spp × Plm	6
	Sol × Spp × Plm × Blk (Error C)	36

[1] Blk = Block, Sol = Soil Series, Spp = Species, Plm = Planting Method.

Table 2
ANOVA Table Used for Bulk Density, Macroporosity, Microporosity, Total Porosity, Saturated Hydraulic Conductivity, Moisture Retention Capacity, and Soil Moisture Desorption Hypothesis Testing

	Source[1]	DF
Main Plot	Blk	3
	Dep	2
	Dep × Blk (Error A)	6
Split Plot	Sol	2
	Dep × Sol	4
	Dep × Sol × Blk (Error B)	18
Split-Split Plot	Spp	3
	Dep × Spp	6
	Sol × Spp	6
	Dep × Sol × Spp	12
	Dep × Sol × Spp × Blk (Error C)	36

[1] Blk = Block, Dep = Soil Depth, Sol = Soil Series, Spp = Species.

Pearson product-moment correlations were used to test relationships between measures of seedling performance and environmental factors (SAS Institute, Inc. 1988). First-year seedling and germinant performance, which included survival, height growth, and diameter growth, was evaluated with respect to environmental factors including soil physical properties at depths of 0 to 10, 11 to 20, and 21 to 30 cm, soil chemical properties at a depth of 0 to 30 cm, and herbaceous vegetation biomass. Seedling dieback and sprouting rates and acorn germination and mortality rates were evaluated at 2-week intervals with the corresponding soil water potential at 0 to 30 cm, soil temperature at 0 to 15 cm, and subsurface groundwater level measurements.

3 Results and Discussion

Hydrologic Characterization

Precipitation and soil water status

Onsite precipitation was measured daily from February through June 1992 with cooperation of a local residence. However, measurements were discontinued after June. The nearest local weather stations were located in Yazoo City, which was 26.5 km northeast of the study site, and in Rolling Fork, which was 22.5 km northwest of the study site. Although these local weather stations were some distance from the study site, these data indicated the general trend of precipitation in the area because the available data from the study site and the data from these weather stations showed similar patterns (Figure 5A).

During January and February, the precipitation pattern was frequent events of low to moderate volume. The amount of precipitation gradually decreased toward the end of March and was least during April and May. Precipitation increased in early June and remained consistent through the remainder of the growing season. Overall, total precipitation between January and October 1992 was average, and air temperature was lower than average (Table 3). Precipitation in April and May was lower than average, and precipitation in June and August was higher than average. This precipitation pattern may have been ideal for seedling reestablishment. The relatively dry spring probably minimized seedling mortality commonly associated with flooding and excess moisture, and the relatively wet summer probably minimized seedling mortality commonly caused by moisture deficits.

Soil water status was expressed as water potential (Figure 5B). Since soil water potential was not significantly different among the three soil series, means were pooled across the three soils. Soil water potential followed the precipitation pattern (Figures 5A and 5B). From January to the end of February, water potential gradually increased because of periodic rain and probably because of low evapotranspiration resulting from low temperatures and plant dormancy. The water potential was maximum in early March because of consistent precipitation events, and it gradually decreased as precipitation decreased and as evapotranspiration increased. The declining trend continued

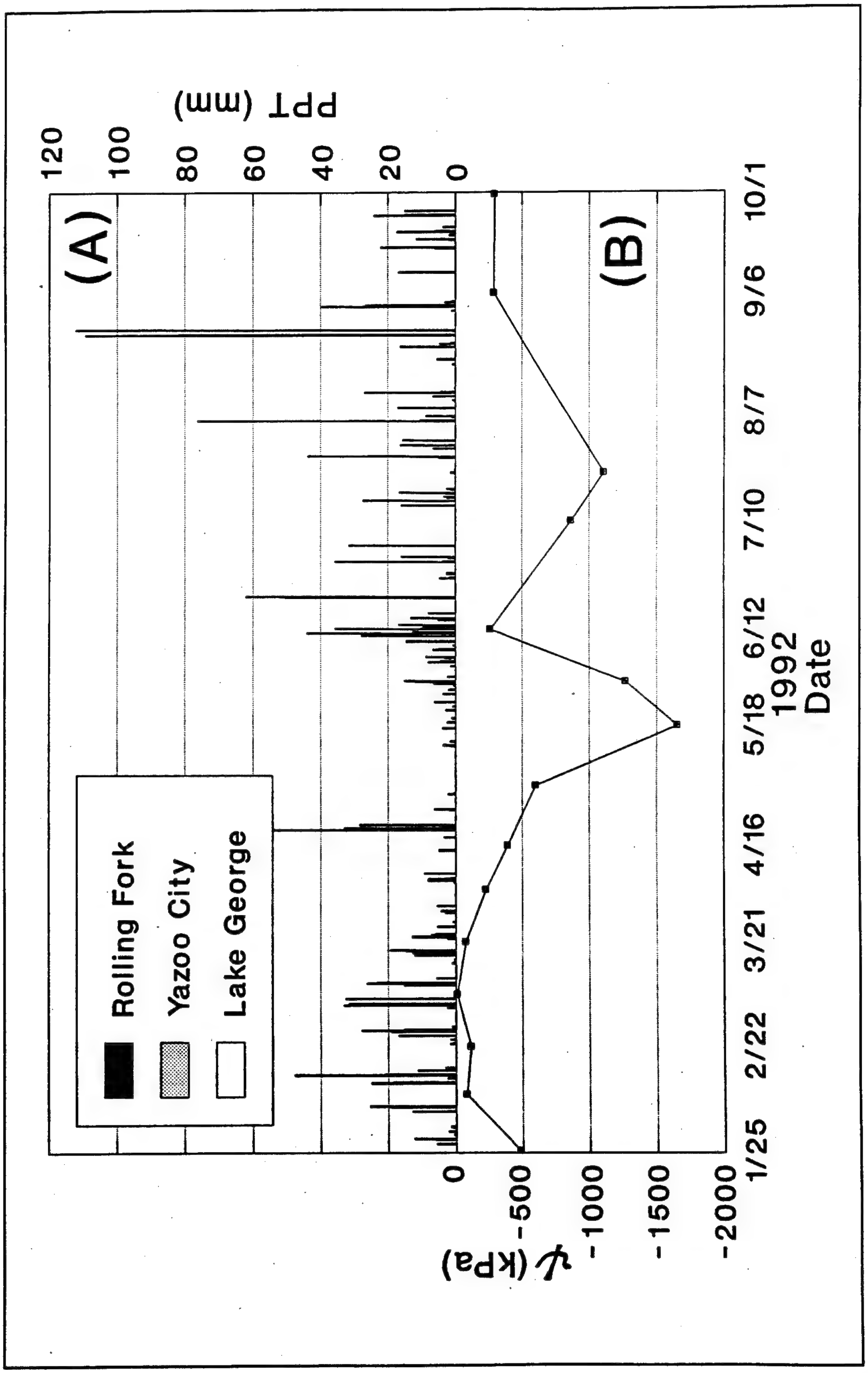


Figure 5. Local precipitation (A) and soil water potential at 0 to 30 cm (B) at Lake George Project site

Table 3
Monthly Mean and 1992 Precipitation and Air Temperature at Rolling Fork, MS, and Yazoo City, MS

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Total
Precipitation, cm month^{-1}											
Rolling Fork mean	13.16	12.24	8.00	12.09	11.86	10.34	10.92	6.68	7.49	9.07	101.9
1992	7.59	14.66	10.74	7.77	3.20	19.35	7.77	21.97	9.27	4.93	107.3
Yazoo City mean	14.02	13.64	16.21	13.49	13.94	9.04	11.46	8.05	8.28	9.88	118.0
1992	8.86	10.82	9.75	7.75	2.39	16.31	11.73	28.02	11.91	2.97	110.5
Air Temperature, °C											
Rolling Fork mean	5.7	8.0	12.7	17.9	22.2	25.9	27.4	26.8	23.8	17.8	–
1992	3.7	7.4	10.2	13.1	17.8	21.5	23.6	20.8	19.2	12.8	–
Yazoo City mean	6.7	9.1	13.8	18.4	22.6	26.3	27.7	27.3	24.5	18.6	–
1992	3.9	7.0	10.8	12.7	16.6	20.9	23.8	20.7	20.1	13.6	–

until the end of May, which was the driest month during the growing season. This dry condition could be critical for plant survival because the water potential in mid-May was lower than the commonly accepted wilting point of -1,500 kPa (Hillel 1982; Kramer and Kozlowski 1979). From June until October, precipitation events were relatively consistent, and the water potential was greater than -1,500 kPa because those events supplied adequate moisture to the soils. Toward the end of the growing season, water potential gradually increased as the temperature and evapotranspiration gradually decreased.

Groundwater wells

Since well lengths were fixed and elevation varied across the study site, each well measured groundwater level at a different elevation (Figure 6). These elevation differences were corrected by the level survey. During the first growing season, subsurface groundwater levels were detected at only six locations in the different period: five of the 3-m wells and a 50-m well that was placed on the site prior to the study (Figure 7). These five 3-m wells were located in low-elevation areas that were in the Sharkey soils in each block and in the Forestdale soil in Block 2 (Figure 6). The actual measurement range of these wells was lower than -3.5 m. The highest subsurface groundwater level, -2.5 m in relative elevation, was measured at the 50-m well in early April. After April, the water table gradually decreased and did not rise above -3 m during the remainder of the first growing season (Figure 7).

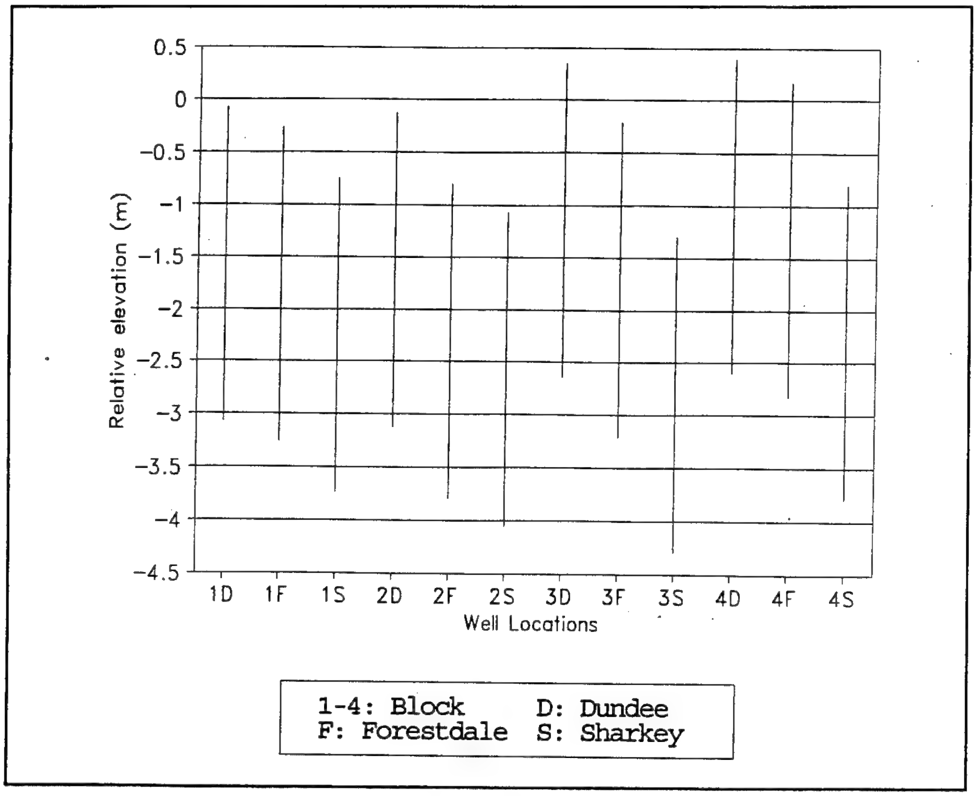


Figure 6. Relative elevation of 3-m well measuring ranges at Lake George Project site

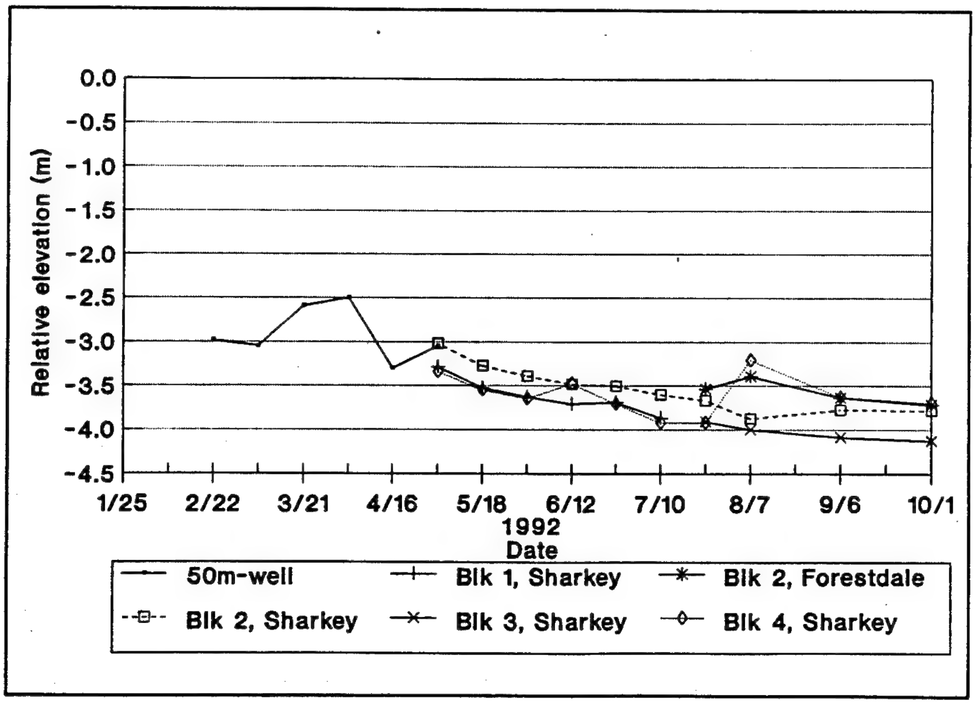


Figure 7. Subsurface groundwater change at Lake George Project site

One-meter wells were installed to measure perched water in the surface soil. However, the wells did not function properly because of the shrink-swell capacity of montmorillonitic clay (Pettry and Switzer 1993). When the clay became dry, it created wide cracks on the surface, and the wells were no longer sealed. When rain started, surface water drained into the well cavities through the cracks because the soil did not swell instantaneously. As a result, water was often observed in the wells when surrounding soil conditions were not saturated.

Flooding

No flooding was observed at the study site during the 1992 growing season. The lack of observable surface water may be a reason that erosion and deposition patterns were not more prevalent.

Competition

The dry weight of herbaceous vegetation biomass in mid-July was 2,523 kg/ha in Dundee, 2,468 kg/ha in Forestdale, and 1,478 kg/ha in Sharkey soils (Table 4). Dry-weight biomass in the Dundee and Forestdale soils was significantly higher than in the Sharkey soil. Johnson and Krinard (1985b) reported that herbaceous competition control improved planted oak seedling height and diameter growth because herbaceous control improved light availability to the seedlings. However, they also mentioned that oak seedlings could grow even if they were overtopped by herbaceous vegetation. They did not report the quantity of herbaceous biomass that affected oak seedling growth.

Table 4
Herbaceous Biomass Measured in Mid-July in Three Lower Mississippi Valley Alluvial Soils[1]

	Dundee	Forestdale	Sharkey
Biomass[2] kg ha^{-1}	2,523.4 a[3] (225.0)[4]	2,467.7 a (212.0)	1,477.8 b (139.1)

[1] Values are means of 32 samples.
[2] Measured by 1-m^2 clip plot.
[3] Means followed by the same letter within a row are not significantly different at the 0.05 level.
[4] Standard error of the mean.

The major herbaceous species at the study site were aster (*Aster exilis*, Ell.),[1] dog-fennel (*Eupatorium capillifolium*, (Lam.) Small), late boneset (*E. serotinum*, Michaux.), horseweed (*Erigeron canadensis*, L.), pitted morning-glory (*Ipomoea lacunosa*, L.), willow-weed (*Polygonum lapathifolium*, L.), curly-dock (*Rumex crispus*, L.), coffeebean (*Sesbania exaltata*, (Raf.) Rydberg ex A.W. Hill), Johnson grass (*Sorgum halapense*, (L.) Persoon), cocklebur (*Xanthium strumarium*, L.). Natural invasion of woody species including box-elder (*Acer negundo*, L.), common persimmon (*Diospyros virginiana*, L.), American sycamore (*Platanus occidentalis*, L.), black willow (*Salix nigra*, Marsh.), pecan (*Carya illinoensis*, (Wang.) K. Koch), trumpet creeper (*Campsis radicans*, (L.) Seemann), eastern baccharis (*Baccharis halimifolia*, L.), and buttanbush (*Cephalanthus occidentalis*, L.) was also observed. Some of the major herbaceous species observed at the study site, such as coffeebean, had not reached maturity when the biomass samples were taken. Therefore, the biomass would be different at other sampling dates.

Soil Characterization

Soil physical properties

Particle-size analysis. Soil physical properties reflected the alluvial gradient at the study site. The Sharkey series contained 73.1-percent clay, which was significantly higher than the clay content of the Forestdale and Dundee soils (Table 5). Fine clay particles are deposited in low, flat, poorly drained landscape positions where Sharkey soils occur. In contrast, the Dundee soil had the highest sand content and lowest clay content (Table 5). This can be explained by the relatively elevated landscape position of Dundee soils.

Table 5
Soil Particle-Size Analysis of Three Lower Mississippi Valley Alluvial Soils[1]

Particle-Size,[2] %	Dundee	Forestdale	Sharkey
Sand	30.7 a[3](3.0)[4]	15.0 b (1.9)	6.2 b (1.4)
Silt	28.6 a (1.4)	34.5 a (1.3)	20.7 a (1.6)
Clay	40.7 b (2.6)	50.5 b (1.3)	73.1 a (2.8)

[1] Values are means of 32 composite samples.
[2] Measured at 0- to 30-cm depth.
[3] Means followed by the same letter within a row are not significantly different at the 0.05 level.
[4] Standard error of the mean.

---

[1] All scientific names and author names of herbaceous vegetation are based on Radford, Ahles, and Bell (1968).

The Forestdale series, which contained 15.0-percent sand, 34.5-percent silt, and 50.5-percent clay, had transitional particle-size distribution between the Sharkey and Dundee series.

Bulk density. Bulk density for the three soils was lowest in the surface 0 to 10 cm and had maximum increase within the 11- to 20-cm depth (Table 6). There were only slight changes in bulk density between the 11- to 20-cm depth and the 21- to 30-cm depth for the three soils. Within the surface

Table 6
Physical Properties of Three Lower Mississippi Valley Alluvial Soils[1]

Property	Dundee	Forestdale	Sharkey
0- to 10-cm Depth			
BD,[2] Mg m^{-3}	1.40 a[3] (0.02)[4]	1.43 a (0.02)	1.26 b (0.03)
Macroporosity, %	7.1 a (1.3)	6.7 a (1.6)	4.0 b (1.5)
Microporosity, %	44.1 b (1.5)	46.3 b (1.6)	56.8 a (1.9)
Total porosity, %	51.2 b (1.2)	53.0 b (1.3)	60.7 a (1.4)
K_{sat},[5] cm day^{-1}	104.9 a (17.7)	122.6 a (31.8)	27.9 a (20.2)
MRC,[6] kg kg^{-1}	0.071 a (0.003)	0.083 a (0.005)	0.082 a (0.004)
11- to 20-cm Depth			
BD, Mg m-3	1.57 a (0.03)	1.56 a (0.03)	1.33 a (0.05)
Macroporosity, %	4.1 a (1.6)	2.7 a (1.1)	1.2 a (0.2)
Microporosity, %	45.3 b (1.7)	47.4 b (1.3)	57.6 a (2.2)
Total porosity, %	49.4 a (1.6)	50.1 a (0.9)	58.8 a (2.2)
K_{sat}, cm day^{-1}	21.5 a (9.5)	14.4 a (14.2)	2.6 a (2.2)
MRC, kg kg^{-1}	0.056 b (0.003)	0.067 a (0.003)	0.074 a (0.005)
21- to 30-m Depth			
BD, Mg m^{-3}	1.61 a (0.04)	1.53 a (0.03)	1.34 a (0.06)
Macroporosity, %	2.7 a (0.010)	2.9 a (0.010)	3.0 a (0.008)
Microporosity, %	45.6 a (0.016)	49.0 a (0.015)	57.1 a (0.028)
Total porosity, %	48.3 b (0.017)	51.9 ab (0.011)	60.1 a (0.027)
K_{sat}, cm day^{-1}	5.7 a (5.5)	15.6 a (13.6)	0.09 a (0.025)
MRC, kg kg^{-1}	0.053b (0.004)	0.070 a (0.005)	0.075 a (0.005)

[1] Values are means of 16 samples.
[2] Bulk density. Mean gravimetric moisture content of Dundee, Forestdale, and Sharkey was 25, 28, and 39 percent, respectively.
[3] Means followed by the same letter within a row are not significantly different at the 0.05 level.
[4] Standard error of the mean.
[5] Saturated hydraulic conductivity.
[6] Moisture retention capacity, which is the difference in gravimetric moisture content between -33 kPa and -1,500 kPa.

10 cm, bulk density values of 1.40 Mg m^{-3} for the Dundee soil and 1.43 Mg m^{-3} for the Forestdale soil were significantly higher than the bulk density of 1.26 Mg m^{-3} for the Sharkey soil (Table 6). However, bulk densities within the 11- to 20-cm depth and the 21- to 30-cm depth were not significantly different among the three soils. The average bulk densities across three depths in each soil in this study were higher than values reported by Broadfoot (1976) for the same soil series on forested sites. Since this study site has been intensively farmed using heavy, large mechanical equipment, it is likely that a plow layer has developed that could increase the bulk density. In addition, because of the high shrink-swell capacity of the soils (Pettry and Switzer 1993), the differences in bulk density may be caused by differences in soil moisture content when samples were collected. Broadfoot (1976) did not report soil moisture levels for bulk density samples.

Macroporosity, microporosity, and total porosity. Porosity properties of the three soil series followed their textural- and bulk-density gradients (Tables 5 and 6). Macroporosity of the Dundee (7.1 percent) and Forestdale (6.7 percent) soils was significantly higher than that of Sharkey soil (4.0 percent) within the surface 10 cm. However, macroporosity below 10 cm was not significantly different among the three soils. The average macroporosity values across three depths in each soil in this study were approximately one-half of those reported by Broadfoot (1976) for the same soil series occurring in forested conditions. This decrease in macroporosity is further evidence that soil compaction from intensive farming practices occurred on this site.

The microporosity of the Sharkey soil at depths of 0 to 10 and 11 to 20 cm was significantly higher than that of the Dundee and Forestdale soils (Table 6). This was probably the result of the high surface area and pore space associated with the high clay content of the Sharkey soil. These relatively high levels of microporosity contribute to the lower bulk density measured in the Sharkey soil.

Total porosity is the sum of macroporosity and microporosity. The high microporosity of the Sharkey soil at 0 to 10 cm resulted in a total porosity of 60.7 percent, which was significantly higher than the 53.0 and 51.2-percent total porosity of Forestdale and Dundee soils, respectively (Table 6). Total porosity was not significantly different among the three soils at depths below 10 cm.

Saturated hydraulic conductivity. Saturated hydraulic conductivity ($K_{sat.}$) was highest within the 0- to 10-cm depth for the three soils because of lower bulk density and higher macroporosity (Table 6). Sharkey soils had the lowest $K_{sat.}$ at all three depths because of high clay content (Table 6). However, these results were not significantly different within depths because of the high variability among samples. The test results in each soil series could be divided into low- and high-$K_{sat.}$ groups. Sixty percent of the Dundee samples, sixty-seven percent of the Forestdale samples, and ninety percent of the Sharkey samples had $K_{sat.}$ values less than 1 cm day^{-1}. However, 38 percent of the Dundee samples, 25 percent of the Forestdale samples, and 4 percent of the

Sharkey samples had $K_{sat.}$ values higher than 80 cm day^{-1}. This variability was caused by soil cracks and root channels, which were located predominantly within the surface 0 to 10 cm.

Hydraulic conductivity is a critical property for seedling survival in soils that are susceptible to inundation. Poor drainage, resulting from low hydraulic conductivity, increases the frequency and duration of soil saturation. Bottomland hardwood seedling mortality is often positively correlated with the frequency and duration of soil saturation (Bonner 1966; Harms 1973; Pezeshki 1991). Therefore, these low $K_{sat.}$ values indicate the potential for high seedling mortality if flooding occurs.

Moisture retention capacity. Moisture retention capacity is a measurement of soil water availability to plants and is calculated by the difference in gravimetric moisture content between soil water potential of -33 kPa and -1,500 kPa (Richards 1965). Moisture retention capacity is a function of soil texture, mineralogy, organic matter content, and bulk density. High clay content soils have a larger surface area that can hold more water by adhesion. Since the Dundee soil had the lowest clay content, its moisture retention capacity was significantly lower than the other soils at 11- to 20- and 21- to 30-cm depths (Table 6). The lower moisture retention capacity of the Dundee soil could become a limiting factor to seedling establishment under less favorable precipitation conditions.

Soil chemical properties

Soil reaction, extractable inorganic nitrogen, and zinc levels were not significantly different among the three soil series (Table 7). Furthermore, although extractable phosphorus content in the Sharkey soil was approximately fourfold greater than the Dundee soil and threefold greater than the Forestdale soil, these differences were not statistically significant because of high variability (Table 7). Significant differences among the three soils occurred for exchangeable potassium, calcium, magnesium, and organic matter. These exchangeable nutrients and organic matter in the Dundee and Forestdale soils ranged from approximately one-half to two-thirds of those in the Sharkey soil (Table 7). This can be attributed to the high clay and organic matter content of the Sharkey soil that creates high cation exchange capacity. Soil comparisons of chemical properties were complicated by spatial variability of the soils and different cropping and fertilization histories.

Nutrient critical levels for bottomland oak species have not been reported in the literature, and foliar nutrient levels were not analyzed in this study. Therefore, it was difficult to accurately evaluate the effect of soil chemical properties on oak seedling performance. Visual symptoms of nutrient deficiencies in the four oak species were not observed during the first growing season in any of the soils.

Table 7
Chemical Properties of Three Lower Mississippi Valley Alluvial Soils[1]

Property[2]	Dundee	Forestdale	Sharkey
pH	5.4 a[3] (0.06)[4]	5.5 a (0.05)	5.7 a (0.05)
Total N,[5] mg kg^{-1}	585 a (28.3)	934 a (65.8)	1,135 a (70.6)
NH_4-N,[6] mg kg^{-1}	5.47 a (0.24)	7.42 a (0.37)	6.82 a (0.38)
NO_3-N,[7] mg kg^{-1}	2.29 a (0.39)	1.64 a (0.43)	0.53 a (0.14)
P,[8] mg kg^{-1}	8.20 a (0.70)	9.61 a (0.65)	31.48 a (3.80)
K,[9] mg kg^{-1}	142.4 b (7.7)	159.9 b (4.6)	240.0 a (10.5)
Ca,[10] mg kg^{-1}	2,213 b (156.2)	2,569 b (81.4)	4,039 a (203.9)
Mg,[11] mg kg^{-1}	610 b (49.8)	792 ab (32.5)	1,047 a (50.8)
Zn,[12] mg kg^{-1}	2.99 a (0.98)	14.0 a (3.97)	9.22 a (2.36)
OM,[13] mg g^{-1}	8.5 b (0.31)	10.6 b (0.34)	15.9 a (0.54)

1 Values are means of 32 composite samples.
2 Measured at 0- to 30-cm depth.
3 Means followed by the same letter within a row are not significantly different at the 0.05 level.
4 Standard error of the mean.
5 N analysis by Kjeldahl method.
6 Extractable NH_4-Nitrogen.
7 Extractable NO_3-Nitrogen.
8 Extractable Phosphorous.
9 Exchangeable Potassium.
10 Exchangeable Calcium.
11 Exchangeable Magnesium.
12 Exchangeable Zinc.
13 Organic matter.

Seedling and Acorn Performance

Controlled seedling and acorn viability tests

Cherrybark oak and Nuttall oak seedling viability test results were 100 percent, and Shumard oak and water oak results were 83 and 92 percent, respectively (Table 8). The acorn viability test resulted in 91-percent germination for Shumard oak, 87-percent for Nuttall oak, 86-percent for water oak, and 79-percent for cherrybark oak. Results of the seedling and acorn viability tests illustrated the high survival potential for both planting methods and all species prior to field planting.

Table 8
Controlled Seedling and Acorn Viability Test Results of Four Bottomland Oak Species

Species	Seedling,[1] %	Acorn,[2] %
Cherrybark oak	100	79
Nuttall oak	100	87
Shumard oak	83	91
Water oak	92	86

[1] Values are means of 12 samples.
[2] Values are means of 200 samples.

Seedling and germinant survival

Seedling and germinant survival results were pooled among the three soil series because soil treatment effects were not significantly different and there were no significant soil × species interactions. The lack of soil treatment effects on survival suggests that differences in soil physical and chemical parameters were not sufficient to cause survival differences. Furthermore, soil moisture levels were not different among soils. This suggests that similar survival levels may be a function of adequate soil moisture throughout the growing season in all three soil series.

Seedling survival at the end of the first-growing season was 82 percent for cherrybark oak, 84 percent for Nuttall oak, 71 percent for Shumard oak, and 78 percent for water oak (Table 9), and these were not significantly different.

Table 9
First-Year Survival and Growth of Four Bottomland Oak Species in Lower Mississippi Valley Alluvial Soils[1]

Species	Planted Seedlings		Acorn Germinants		
	Survival %	Height Growth, cm	Survival %	Height Growth, cm	Diameter Growth[2]
Cherrybark oak	82 a[3]	9.7 b	45 b[4]	8.7 c	0.18 c
Nuttall oak	84 a	19.0 a	72 a[4]	17.0 a	0.36 a
Shumard oak	71 a	9.2 b	73 a	10.5 b	0.24 b
Water oak	78 a	17.8 a	66 a	7.9 c[4]	0.16 c

[1] Values are means of 12 split-split plots.
[2] Groundline diameter.
[3] Means followed by the same letter within a column are not significantly different at the 0.05 level.
[4] Significant difference at the 0.05 level between planting methods.

The lower survival of Shumard oak seedlings in the field and in the control test might be caused by excessive pruning of the root systems of this species when seedlings were lifted from the nursery beds. Other studies also showed high seedling survival of these four oak species on similar sites (Francis 1983; Krinard and Kennedy 1981, 1987; Kennedy and Krinard 1985; Kennedy, Krinard, and Schlaegel 1987). The expected seedling survival of bottomland oak species according to these studies was generally 75 to 90 percent.

The germinant establishment of cherrybark, Nuttall, Shumard, and water oak was 45, 72, 73, and 66 percent, respectively (Table 9). Cherrybark oak germinant survival was significantly lower than the other species and was significantly lower than cherrybark-planted seedling survival (Table 9). However, Johnson and Krinard (1985b) reported that only 36 percent of cherrybark oak acorns germinated in a silty upland soil. They suggested that cherrybark oak germination success rates of only 30 to 40 percent were common. This indicated that 45-percent germinant survival in this study was relatively high.

Seedling and germinant growth

Soil series effects and species × soil series interactions were not significant for measured growth parameters; therefore, growth results were pooled among the soil series. Seedling height growth of cherrybark, Nuttall, Shumard, and water oaks was 9.7, 19.0, 9.2, and 17.8 cm, respectively (Table 9). Nuttall and water oak seedlings grew twofold greater than cherrybark and Shumard oak seedlings. Seedling diameter growth was not reported because of the difficulty in accurately measuring the initial groundline diameter when the soil surface was unsettled after planting.

Germinant height growth of cherrybark, Nuttall, Shumard, and water oaks was 8.7, 17.0, 10.5, and 7.9 cm, respectively. Nuttall oak germinant height growth was significantly higher than other germinants, and cherrybark and water oak germinant height growth was significantly lower than Nuttall and Shumard oak germinants. Only water oak height growth was significantly different with respect to planting methods. Planted water oak seedlings had height growth that exceeded germinant height growth by 125 percent (Table 9). The greater height growth of planted and direct-seeded Nuttall oak and of planted water oak seedlings could be advantageous for avoiding total inundation on sites susceptible to flooding.

Germinant diameter growth followed the same order as germinant height growth. Nuttall oak diameter growth (0.35 cm) was the highest followed by Shumard oak (0.24 cm), cherrybark oak (0.18 cm), and water oak (0.16 cm) (Table 9).

Relationship Between Plant Performance and Environmental Factors

Soil temperature, soil water potential, and acorn germination

Soil temperature and moisture are the major factors controlling acorn germination (Kramer and Kozlowski 1979). Percent germination is the sum of cumulative germination, germinant mortality, and sprouting at a given date (Figure 8C). Since there were not significant soil series effects or soil × species interactions for percent germination, the values were pooled among soils for each date. Furthermore, soil temperature and soil water potential were not significantly different among soils, so these values were also pooled among soils for each date (Figures 8A and 8B).

Germination of Shumard and cherrybark oaks was first observed in late April when soil temperature exceeded 20 °C (Figures 8A and 8C). The average germination rate of Shumard oak during late April to early May was 1.8 percent day^{-1} (Figure 9), and percent germination of Shumard oak on May 18 was 59 percent. The germination rate of cherrybark oak started at 0.8 percent day^{-1}, and it dropped to 0.4 percent day^{-1} when soil water potential dropped in late May (Figure 9). Germination rates for Shumard oak decreased by early June, and germination rate for cherrybark oak decreased by early July (Figure 9). The percent germination for these two species remained the same for the duration of the growing season (Figure 8C). In contrast, germination of Nuttall and water oaks was not observed until mid-May (Figure 8C). The germination rate of Nuttall oak was relatively high (0.9 percent day^{-1}) through early July and then decreased during the remainder of the growing season (Figure 9). Water oak germination started slowly, then steadily increased through the remainder of the growing season (Figure 8). The peak germination rate of 0.8 percent day^{-1} for water oak occurred in early July (Figure 9). The germinant mortality rate had little effect on overall percent germination because of the low mortality rate throughout the growing season (Figure 10).

These results show two germination patterns: (a) rapid germination and early seedling establishment of Shumard and cherrybark oaks with most occurring by midgrowing season; and (b) later starting time followed by steady germination of Nuttall and water oaks throughout the growing season. Johnson and Krinard (1985b) observed similar germination patterns for Nuttall and water oaks in previously cultivated Mississippi Delta soils.

Germinant survival after the first growing season was relatively high for all four species (Table 9) compared with other studies on similar sites (Johnson and Krinard 1985a,b). This can be attributed to favorable precipitation patterns and soil moisture conditions. Soil water potential in each soil decreased for brief periods in May and July (Figure 8B), but this had little effect on germination or mortality rates (Figures 9 and 10). As a result, overall germinant survival was high for all species (Figures 5B and 5C).

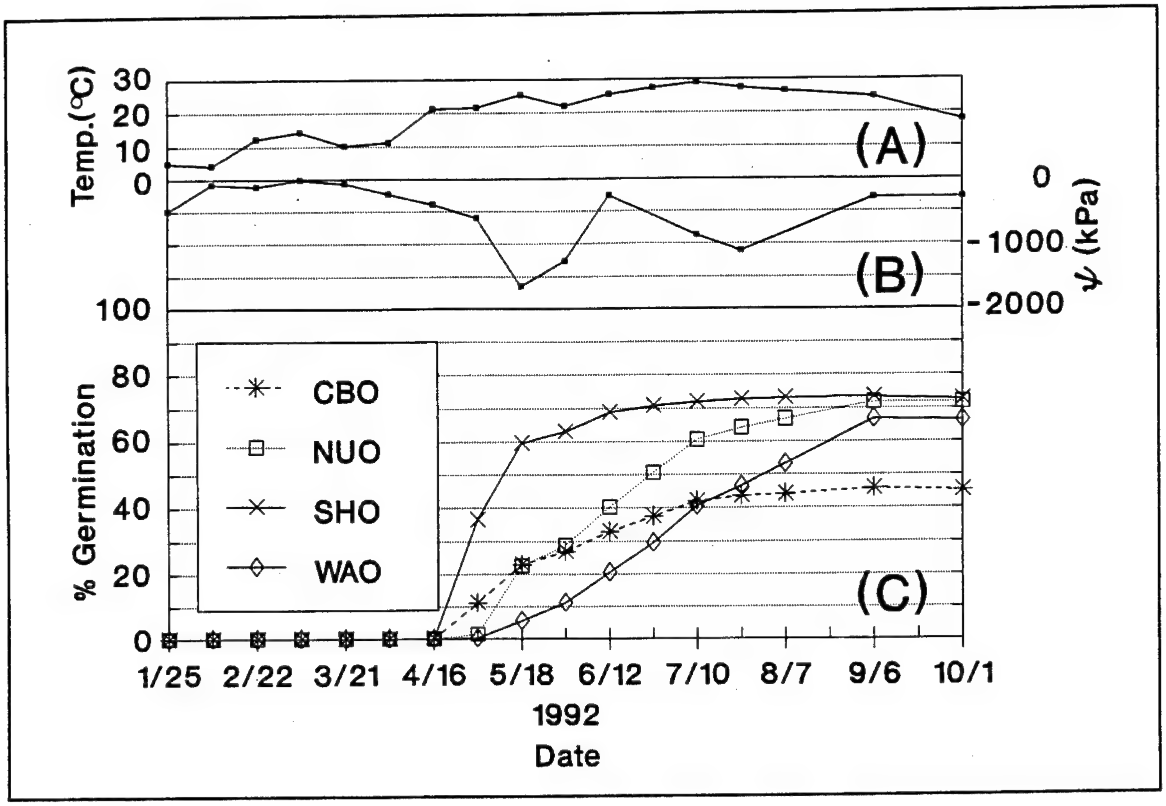


Figure 8. Relation among soil temperature (A), soil water potential (B), and percent germination of bottomland oak species (C) in lower Mississippi Valley alluvial soils

Soil water potential and seedling survival

Planted seedling survival is the percentage of living seedlings at each measurement date. Dieback and sprouting accounted for fluctuations in percent survival during the growing season (Figure 11B). However, there were only slight increases or decreases in survival for any of the species between the initial measurement in May and the final measurement in October. Water oak had a high seedling mortality rate, which was 0.18 percent day^{-1} between June 12 and June 25 (Figure 12), and Shumard oak had the highest seedling sprouting rate, which was 0.28 percent day^{-1} between June 12 and June 25 (Figure 13). The spouting of Shumard oak might be related to excessive root pruning, which could cause an imbalance in the root/shoot ratio.

Soil moisture deficits that occurred in May and July had very little effect on seedling mortality (Figures 11A, 11B, and 12). This shows that hydrologic and edaphic conditions in the first-growing season did not limit planted seedling survival. It also suggests that most of the seedling mortality probably occurred during storage, planting, or prior to bud break in the spring.

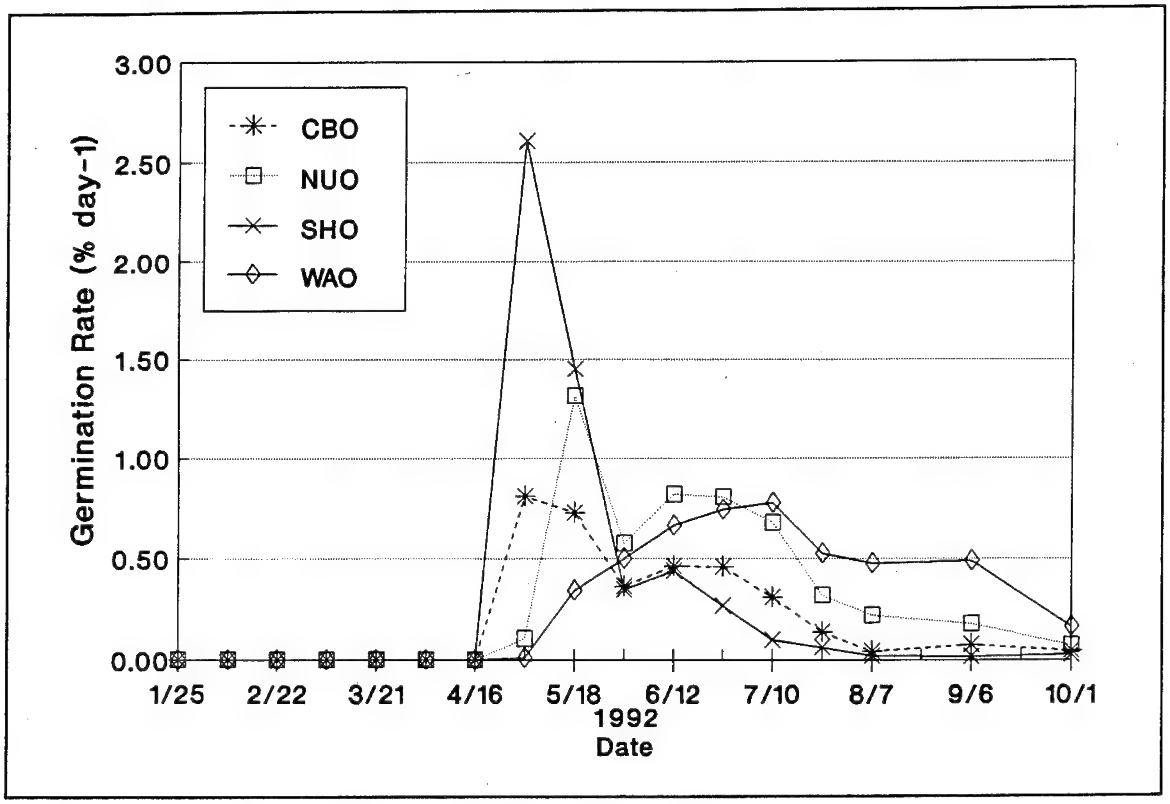


Figure 9. Germination rate of bottomland oak species in lower Mississippi Valley alluvial soils

Correlations Between Seedling Performance and Environmental Factors

Seasonal results

Nuttall oak seedling survival was negatively correlated with macroporosity at 0- to 10-cm depth and was positively correlated with microporosity at 0- to 10-cm depth and total porosity at 11- to 20-cm depth (Appendix A, Table A1). This indicates that Nuttall oak seedling survival was high with low macroporosity and high microporosity and total porosity. These conditions were most prevalent in the Sharkey soil. Survival of Nuttall oak seedlings was 80 percent in the Sharkey series, 79 percent in the Forestdale series, and 75 percent in the Dundee series. Survival of Nuttall oak was negatively correlated with levels of soil NO_3-N and herbaceous biomass. Survival of cherrybark oak was negatively correlated with soil zinc. It is difficult to explain the negative correlation between NO_3-N or zinc and survival. However, increasing levels of biomass could cause decreased Nuttall oak survival because of competition for light, nutrients, and moisture. Seedling survival was not correlated with any other measured parameters (Appendix A, Table A1).

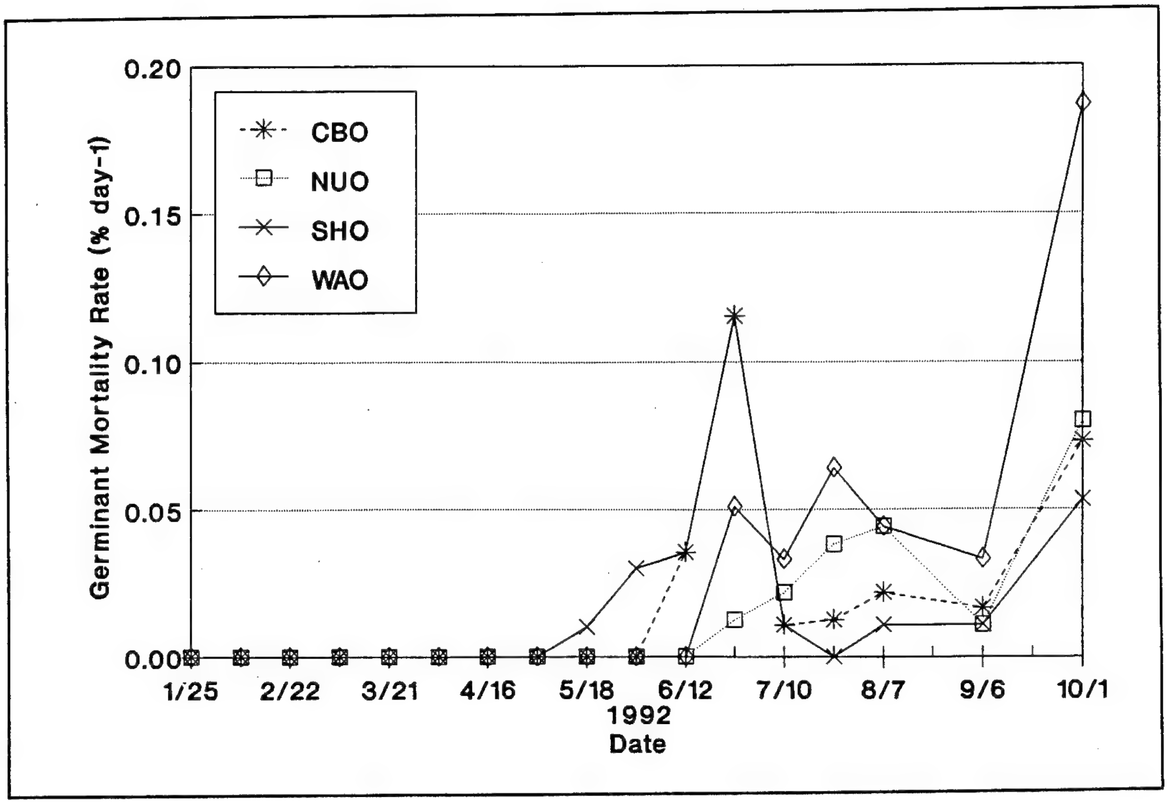


Figure 10. Germination mortality rate of bottomland oak species in lower Mississippi Valley alluvial soils

Shumard oak seedling height growth showed some sensitivity to soil properties. Height growth was positively correlated with sand content, bulk density at 0 to 10 cm, and soil NO_3-N, and negatively correlated with clay content, microporosity at 0 to 10 cm, and soil magnesium (Appendix A, Table A1). This suggests that Shumard oak seedling growth might be favored on the Dundee soil, which had relatively high sand content, low clay content, and low microporosity. The average height growth of Shumard oak seedlings in Dundee, Sharkey, and Forestdale soils was 11.25, 8.3, and 8.2 cm, respectively.

Germinant survival of all four oak species was negatively correlated with macroporosity and $K_{sat.}$ (Appendix A, Table A1). This suggests that the slower drainage and more moisture retention associated with these two soil physical properties may be beneficial for germinant survival, especially under dry weather condition. Soil chemical properties and herbaceous biomass were not correlated with germinant survival.

Germinant height growth had few significant and explainable correlations with measured environmental parameters (Appendix A, Table A1). In contrast, diameter growth of germinants showed higher sensitivity to soil physical and chemical properties (Appendix A, Table A1). For example, germinant diameter growth was positively correlated with clay content, microporosity, and total porosity, and negatively correlated with bulk density and macroporosity

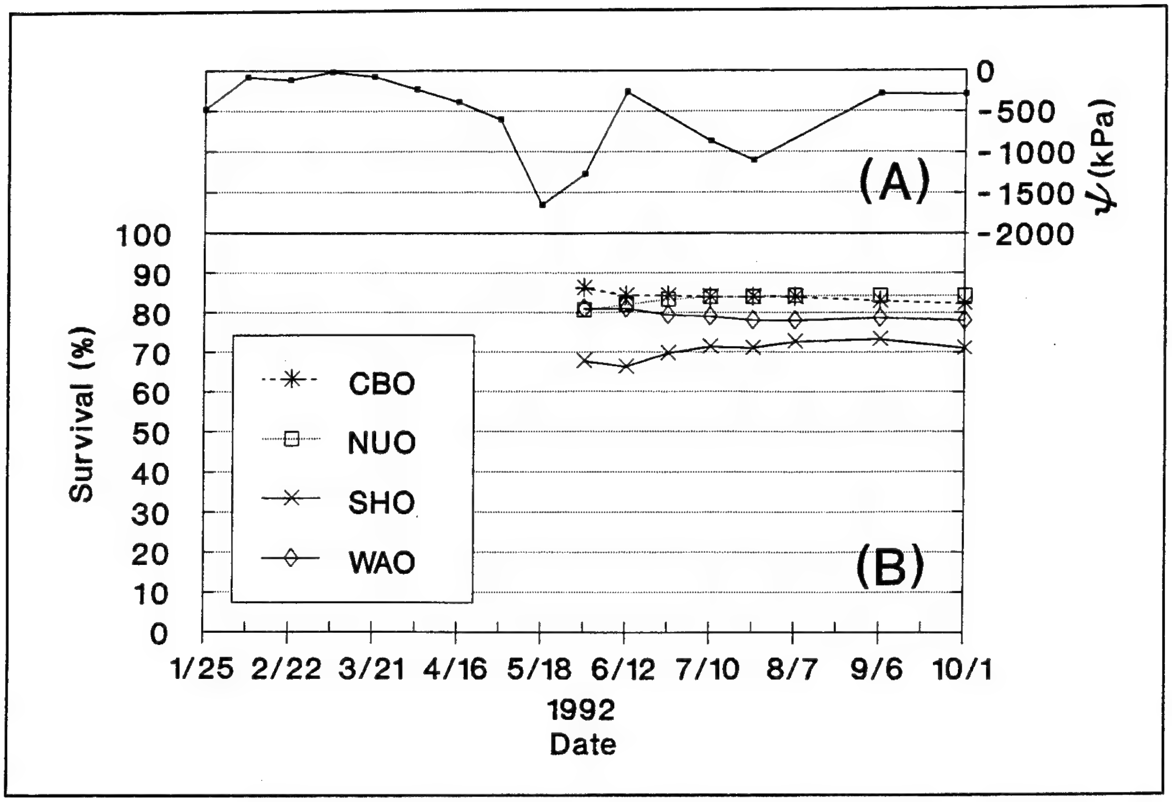


Figure 11. Soil water potential (A) and percent seedling survival of bottomland oak species (B) in lower Mississippi Valley alluvial soils

(Appendix A, Table A1). This is further evidence that soil physical properties that promote moisture retention are important for oak reestablishment success. Exchangeable potassium, calcium, and magnesium were also positively correlated with germinant diameter growth (Appendix A, Table A1). This suggests that nutrient balances between these cations and the commonly limiting nutrients such as N and P may be a factor in germinant performance.

Biweekly results

Seedling dieback rates of Nuttall, Shumard, and water oak were negatively correlated with soil water potential towards the end of the growing season in September and October (Appendix A, Table A2). This suggests that for most of the growing season, levels of measured soil factors did not affect seedling mortality. Seedling sprouting showed few correlations with soil moisture, temperature, or water table levels (Appendix A, Table A2). Oak germination showed no explainable correlations with soil properties with the exception of a positive correlation between soil temperature and Shumard oak germination in early May (Appendix A, Table A2). However, the mortality rate of germinants did show some correlation to soil temperature levels (Appendix A, Table A2). Cherrybark oak germinant mortality rate was positively correlated with soil temperature in June, and Shumard oak germinant mortality rate was

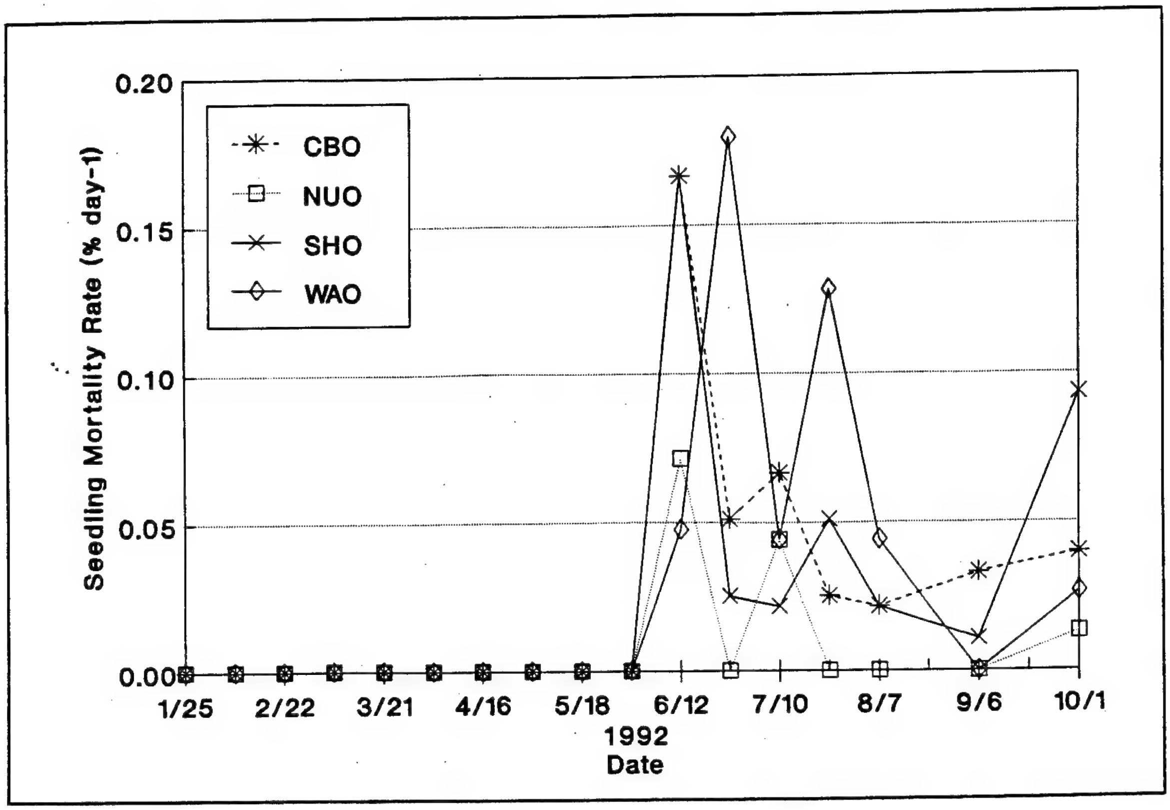


Figure 12. Seedling mortality rate of bottomland oak species in lower Mississippi Valley alluvial soils

positively correlated with soil temperature in June and August. Furthermore, low soil temperatures in September and October were correlated with increased germinant mortality rates of water oak and cherrybark oak, respectively (Appendix A, Table A2). This was probably because some new germinants were damaged by cool weather in the fall.

The lack of soil water potential effects on oak seedling and acorn performance during this first growing season illustrates that precipitation amounts and frequency were adequate to minimize soil moisture deficits that can limit survival. However, germinant sensitivity to soil physical properties suggests that if moisture conditions were less favorable, reestablishment would have been more responsive to moisture fluctuations.

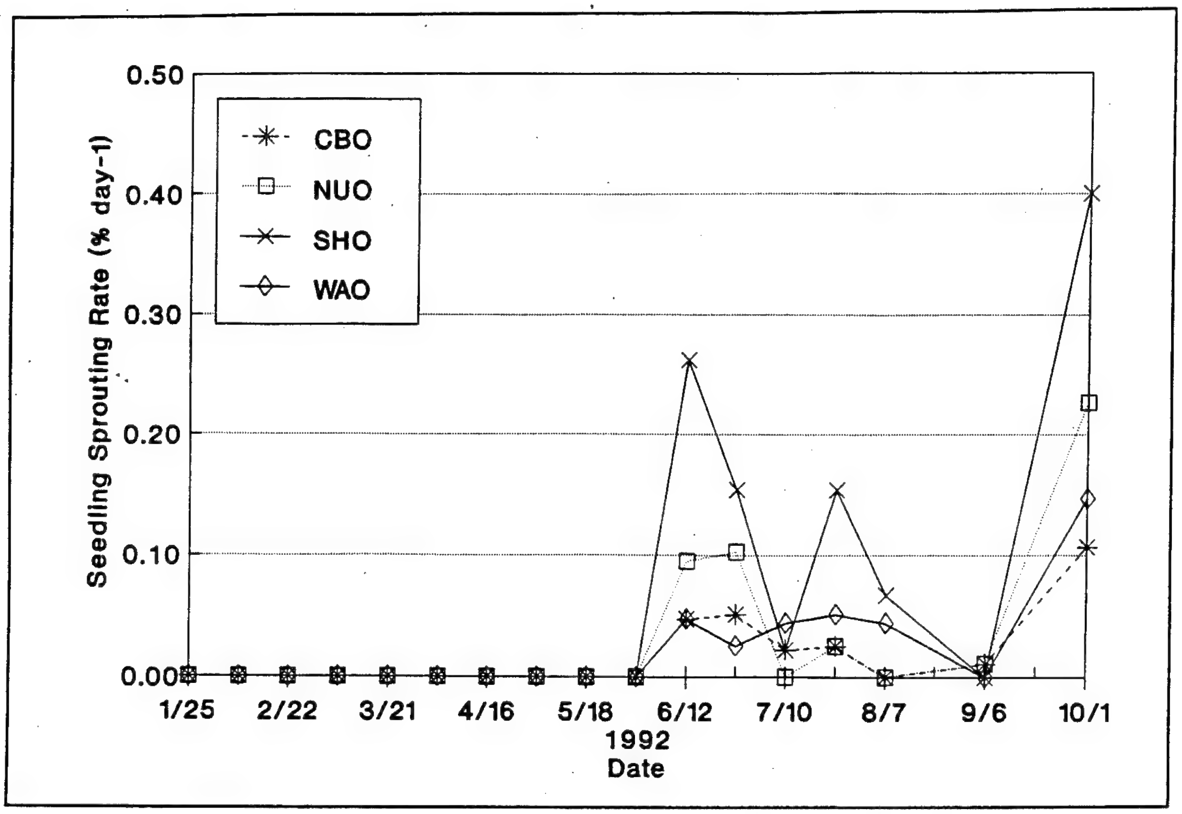


Figure 13. Seedling sprouting rate of bottomland oak species in lower Mississippi Valley alluvial soils

4 Conclusions

Wetland restoration efforts in the lower Mississippi Valley often include reestablishment of bottomland hardwood species, especially oaks. However, success of oak establishment is inconsistent. There is a need for information on relationships among seedling growth, planting methods, soil properties, and hydrologic conditions to promote these wetland restoration projects. The objective of this study was to evaluate the influence of these factors on oak seedling performance on a site being converted from farmland to forestland. Seedlings and acorns of cherrybark oak (*Quercus pagoda* Raf.), Nuttall oak (*Q. nuttallii* Palmer), Shumard oak (*Q. shumardii* Buckl.), and water oak (*Q. nigra* L.) were planted in three common alluvial soils. A lack of spring flooding and adequate soil moisture during the growing season resulted in high first-year seedling survival in each soil using either seedling planting or direct seeding of the four oak species. Nuttall and water oaks germinated throughout the growing season under different soil moisture conditions. This adaptability may be critical when site conditions are less favorable than they were during the first year of this study. Rapid height growth of planted Nuttall and water oak seedlings and of direct-seeded Nuttall oak shows that these species may be less susceptible to submergence by floodwater and subsequent mortality.

References

Bonner, F. T. (1966). "Survival and first-year growth of hardwoods planted in saturated soil," Res. Note SO-32, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

Bonner, F. T., and Vozzo, J. A. (1987). "Seed biology and technology of *Quercus*," Gen. Technical Report SO-66, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

Brady, N. C. (1984). *The nature and properties of soils.* Macmillan Publishing Company, New York.

Broadfoot, W. M. (1976). "Hardwood suitability for and properties of important Midsouth soils," Res. Pap. SO-127, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

Burke, D. G., Meyers, E. J., Tiner, R. W., Jr., and Groman, H. (1988). "Protecting nontidal wetlands," American Planning Association, Planning Advisory Service, 412-413.

Council on Environmental Quality. (1978). "Our nation's wetlands," An Interagency Task Force Report, Government Printing Office, Washington, DC.

Debolt, D. C. (1974). "A high sample volume procedure for the colorimetric determination of soil organic matter," *Comm. Soil Sci. Plant Analy.* 5, 131-137.

Duncan, W. H., and Duncan, M. B. (1988). *Trees of the southern United States.* The University of Georgia Press, Athens, GA.

Francis, J. K. (1983). "Cherrybark and Shumard oaks successfully planted in eroded ridges," *Tree Planter's Notes* 34, 28-30.

Gee, G. W., and Bauder, J. W. (1986). "Particle-size analysis." *Methods of soil analysis. Part 1. Physical and mineralogical methods.* 2nd ed., A. Klute, ed., ASA and SSSA, Madison, WI, 383-411.

Harms, W. R. (1973). "Some effects of soil type and water regime on growth of tupelo seedlings," *Ecology* 54, 189-193.

Hill, R. J. (1975). "U.S. Army Corps of Engineers." *Proceedings of the national wetland classification and inventory workshop.* USDI Fish and Wildl. Serv.

Hillel, D. (1982). *Introduction to soil physics.* Academic Press, Inc., San Diego, CA.

Johnson, R. L., and Krinard, R. M. (1985a). "Oak seeding on an adverse field site," Research Note SO-319, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

_________. (1985b). "Oak regeneration by direct seeding," *Alabama's Treasured Forests* 3, 12-5.

Kennedy, H. E., Jr., and Krinard, R. M. (1985). "Shumard oaks successfully planted in high pH soils," Research Note SO-321, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

Kennedy, H. E., Jr., Krinard, R. M., and Schlaegel, B. E. (1987). "Growth and development of four oaks through age 10 planted at five spacings in a minor stream bottom," Proc. Rep. 10, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

Klute, A. (1986). "Water retention: Laboratory methods." *Methods of soil analysis. Part 1. Physical and mineralogical methods.* 2nd ed., A. Klute, ed., ASA and SSSA, Madison, WI, 635-662.

Klute, A., and Dirksen, C. (1986). "Hydraulic conductivity and diffusivity: Laboratory methods." *Methods of soil analysis. Part 1. Physical and mineralogical methods.* 2nd ed., A. Klute, ed., ASA and SSSA, Madison, WI, 687-734.

Kramer, P. J., and Kozlowski, T. T. (1979). *Physiology of woody plants.* Academic Press, Inc., San Diego, CA.

Krinard, R. M., and Kennedy, H. E., Jr. (1981). "Growth and yields of 5-year-old planted hardwoods in Sharkey clay soil," Research Note SO-271, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

_________. (1987). "Planted hardwood development on clay soil without weed control through 16 years," Research Note SO-343, USDA For. Serv. South. For. Exp. Stn., New Orleans, LA.

Kruczynski, W. L. (1989). "Mitigation and the section 404 program: A perspective." *Wetland creation and restoration: The status of the science Vol. II: Perspectives.* J. A. Kusler and M. E. Kentula, ed., U.S. EPA, EPA/600/3-89/038, 137-142.

Lancaster, J. D. (1970). "Soil test calibration and fertilizer recommendations," Miss. Agri. and For. Exp. Stn. Mimeograph, Mississippi State University, MS.

MacDonald, P. O., Frayer, W. E., and Clauser, J. K. (1979). "Documentation, chronology, and future projections of bottomland hardwoods habitat loss in the lower Mississippi alluvial plain, Vol. 1: Basic report," U.S. Fish and Wildl. Serv., Ecological Serv., Vicksburg, MS.

McLean, E. O. (1973). "Testing soils for pH and lime requirement." *Soil testing and plant analysis.* Revised Edition. L. M. Walsh and J. D. Beaton, ed., Soil Sci. Soc. Amer., Madison, WI, 78-95.

Pettry, D. E., and Switzer, R. E. (1993). "Expansive soils of Mississippi," Miss. Agri. For. Exp. Stn. Bull. 986, 29.

Pezeshki, S. R. (1991). "Root responses of flood-tolerant and flood-sensitive tree species to soil redox conditions," *Trees* 5, 180-186.

Radford, A. E., Ahles, H. E., and Bell, C. R. (1968). *Manual of the vascular flora of the Carolinas.* The University of North Carolina Press, Chapel Hill, NC.

Richards, L. A. (1965). "Physical conditions of water in soil." *Methods of soil analysis. Part 1. Aagron. Monogr. 9.* C. A. Black et al., ed., ASA, Madison, WI, 128-152.

SAS Institute, Inc. (1988). *SAS/STAT User's guide, 6.03 ed.* SAS Institute Inc., Cary, NC.

Soil Conservation Service - U.S. Department of Agriculture. (1975). "Soil survey of Yazoo County, Mississippi," Miss. Agric. and For. Exp. Stn.

__________. (1991). "Hydric soils of the United States: In cooperation with the National Technical Committee for Hydric Soils," Miscellaneous Publication No. 1491.

Teare, I. D., and Peet, M. M. (1983). *Crop-water relations.* John Wiley and Sons, New York.

Technicon Industrial Systems. (1973). "Ammonia in water and wastewater," Industrial Method No. 270-73W, Technicon Industrial Systems, Tarrytown, NY.

Turner, R. E., Forsythe, S. W., and Craig, N. J. (1981). "Bottomland hardwood forest land resources of the southern United States." *Wetlands of bottomland hardwood forests*. J. R. Clark and J. Benforado, ed., Elsevier Scientific Publishing Co., Amsterdam, Netherlands, 13-28.

U.S. Army Corps of Engineers. (1990). "Yazoo backwater area mitigation lands Lake George property land acquisition Yazoo Basin, Mississippi," U.S. Army Corps of Engineers, Vicksburg District.

Want, W. L. (1989). *Law of wetlands regulation*. Clark Boardman Comp. Ltd., New York.

Appendix A
Correlation Coefficients Tables

Table A1
Correlation Coefficients Between Bottomland Oak Seedling Performance and Environmental Factors

	Cherrybark	Nuttall	Shumard	Water
Seedling Survival				
Soil Physical Properties				
Macroporosity 1	NS[1]	-0.65464	NS	NS
Microporosity 1	NS	0.71981	NS	NS
Total porosity 2	NS	0.66389	NS	NS
Soil Chemical Properties[2]				
NO_3	NS	-0.65176	NS	NS
Zn	-0.67552	NS	NS	NS
Vegetative Competition				
Biomass	NS	-0.71726	NS	NS
Seedling Height Growth				
Soil Physical Properties				
Sand	NS	NS	0.78981	NS
Silt	NS	NS	NS	NS
Clay	NS	NS	-0.61177	NS
Bulk density 1	NS	NS	0.6401	NS
Microporosity 1	NS	NS	-0.65537	NS
K_{sat} 3	NS	NS	NS	0.62166
Soil Chemical Properties				
NO_3	NS	NS	0.79382	NS
Mg	NS	NS	-0.67413	NS
Germinant Survival				
Soil Physical Properties				
Sand	NS	NS	-0.67835	NS
Bulk density 3	-0.58914	NS	NS	NS
Macroporosity 1	-0.58503	NS	-0.59569	-0.66036
Macroporosity 2	NS	NS	-0.85452	-0.72443
				(Sheet 1 of 3)

[1] NS = Correlation coefficient not significant at the 0.05 level.
[2] 0- to 30-cm soil length.

Table A1 (Continued)				
	Cherrybark	Nuttall	Shumard	Water
Germinant Survival (Continued)				
Soil Physical Properties (Continued)				
Microporosity 3	0.68134	NS	NS	NS
Total porosity 3	0.75625	NS	NS	NS
K_{sat} 1	NS	NS	NS	NS
K_{sat} 2	NS	-0.70485	-0.90374	-0.78699
K_{sat} 3	-0.61566	NS	NS	NS
Germinant Height Growth				
Soil Physical Properties				
Sand	NS	NS	NS	NS
Silt	0.59619	NS	NS	NS
Clay	NS	NS	NS	NS
Total porosity 3	-0.60562	NS	NS	NS
K_{sat} 1	0.66757	NS	NS	NS
Soil Chemical Properties				
pH	-0.61158	NS	NS	NS
K	NS	NS	NS	0.61444
Germinant Diameter Growth				
Soil Physical Properties				
Sand	NS	NS	NS	NS
Silt	NS	-0.68059	NS	NS
Clay	0.61877	NS	0.59788	NS
Bulk density 1	NS	NS	NS	NS
Bulk density 2	NS	NS	-0.63906	-0.61365
Bulk density 3	-0.64495	NS	-0.62996	NS
Macroporosity 1	-0.63897	-0.58068	NS	NS
Macroporosity 2	NS	NS	NS	NS
Macroporosity 3	NS	NS	NS	-0.72175
Microporosity 1	NS	NS	NS	NS
Microporosity 2	NS	NS	0.62017	NS
Microporosity 3	0.63462	NS	0.66449	NS
				(Sheet 2 of 3)

Table A1 (Concluded)

	Cherrybark	Nuttall	Shumard	Water
Germinant Diameter Growth (Continued)				
Soil Physical Properties (Continued)				
Total porosity 1	NS	NS	0.59876	0.72053
Total porosity 2	NS	NS	NS	0.77118
Total porosity 3	NS	NS	0.58697	NS
Soil Chemical Properties				
K	NS	0.62002	0.65358	NS
Ca	0.60482	0.5795	0.61949	NS
Mg	0.65549	NS	NS	NS

(Sheet 3 of 3)

Table A2
Periodic Correlation Coefficients Between Bottomland Oak Seedling Performance and Selected Soil Conditions

	Soil Property	Cherrybark	Nuttall	Shumard
Seedling Dieback Rate				
Water				
06/25/92 Soil temperature	NS	NS	NS	-0.69951
09/06/92 Water potential	NS	NS	-0.7306	NS
10/01/92 Water potential	NS	-0.618	NS	-0.65584
10/01/92 Soil temperature	0.56975	NS	NS	NS
Seedling Sprouting Rate				
06/12/92 Soil temperature	NS	NS	NS	-0.61653
08/07/92 Water table depth	NS	NS	NS	-0.68724
Germination Rate				
05/02/92 Soil temperature	NS	NS	0.57853	NS
06/12/92 Water table depth	NS	NS	0.65461	NS
06/25/92 Water table depth	NS	NS	0.7267	NS
07/23/92 Water table depth	NS	-0.66059	NS	NS
08/07/92 Water table depth	NS	NS	NS	0.58164
10/01/92 Water table depth	NS	-0.71131	NS	NS
Germinant Mortality Rate				
6/12/92 Soil temperature	0.6043	NS	NS	NS
06/25/92 Soil temperature	NS	NS	0.80364	NS
08/07/92 Soil temperature	NS	NS	0.62777	NS
09/06/92 Soil temperature	NS	NS	NS	-0.77743
10/01/92 Soil temperature	-0.68597	NS	NS	NS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1995	Final report

4. TITLE AND SUBTITLE
Reestablishment of Bottomland Oak Species in Lower Mississippi Valley Alluvial Soils

5. FUNDING NUMBERS
WU 32761

6. AUTHOR(S)
Masato Miwa

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Mississippi State University
Mississippi State, MS 39762-9681

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199;
U.S. Army Corps of Engineers, Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Technical Report
WRP-RE-14

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The majority acreage of bottomland hardwood forests in the lower Mississippi Valley have been cleared. Several Government programs now encourage reforestation of formerly cleared areas, especially to large seeded tree species. Research is needed to identify optimal planting methodologies to utilize soil and hydrologic gradients and species diversity if bottomland forests are to be economically reforested and managed. Cherrybark oak, Nuttall oak, Shumard oak, and water oak were direct seeded (December 1991) and seedling planted (March 1992) onto Dundee, Forestdale, and Sharkey soil plots. Replicated treatments were oak species, soil species, and planting methodology. Soil physical, hydrologic, and fertility properties were correlated with plant germination and growth for each species. Optimal soil moisture conditions during the spring and growing season of 1992 enhanced germination, survival, and growth and minimized treatment differences. Nuttall and water oak seemed to exhibit germination and growth patterns that may enhance their survival under more stressful growing conditions. Differences in soil type and planting methodology were generally nonsignificant.

14. SUBJECT TERMS

Bottomland hardwoods	Oaks
Forest restoration	Sharkey soil
Mississippi Delta	Wetland restoration

15. NUMBER OF PAGES
52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		